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THE ORE DEPOSITS OF UTAH

BY

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PREFACE.

By F. L. Ransome.

Twelve years ago, when Mr. Waldemar Lindgren was in charge of the Survey's work on the geology of metalliferous deposits, he planned the preparation of a series of volumes to be published as professional papers, in each of which should be described the geology and ore deposits of a single State. His idea was to summarize and bring up to date such detailed monographic work as had already been done on individual districts, to make reconnaissance examinations of districts that had not been geologically studied, and to extend, by reconnaissance where necessary, our knowledge of the general geology of the State sufficiently to provide an adequate setting for the descriptions of the mining districts. It was realized that at least three general purposes might be fulfilled by these volumes. Each would constitute a convenient reference book of the geology and ore deposits of the State described, wherein one might ascertain what is known of each district and find references, where appropriate, to other publications; each would contain accounts of districts not elsewhere geologically described; finally, the broad survey of all the ore deposits of the State with reference to their geologic history and surroundings would, it might reasonably be expected, result in the discovery of important truths not evident to the geologist whose attention is focused for the time being on a single district. Inasmuch as New Mexico appeared to offer the fewest complications and difficulties, the ore deposits of that State were selected as the subject of the first volume, which appeared in 1910.[1]

This report not only proved widely useful but fulfilled the expectation above referred to in that the work upon which it was based resulted in the recognition of a number of distinct epochs of metallization, and in the determination of the relation of these epochs to one another and of the mineral character and structural features pertaining to each.

The plan so successfully begun has been continued. No member of the Survey has been able to devote all of his time to one of these State reports, but where the work of a geologist has lain more or less continuously in a single State, he has gradually, in connection with his other duties, accumulated material for such a publication.

The present report on Utah by Mr. Butler and others is the second of the series to appear. Another on Idaho is well advanced, and one on Arizona will probably follow, although its actual compilation can scarcely be said to have begun.

In the development and output of its mines and in the mineralogic variety of its ores, Utah far surpasses New Mexico. The State also contains a large number of less-developed districts concerning which little geologic information has hitherto been available. Both of these facts, in spite of persistent efforts at condensation on the part of the authors, have favored the growth of the present volume to a size which may, by some, be considered unwieldy. It is felt, however, that one function of the report, that of a reference work to which a reader might turn for information about a particular district, would be impaired if the more famous and productive districts were less fully described or if the accounts of the little-known districts were lacking in those details which, perhaps, Mr. Butler and his associates are best able to supply.

An interesting result which has come from the general survey of all the known ore deposits of the State is the generalization by Mr. Butler that the occurrence of ore bodies around an intrusive stock, within depths accessible to mining, depends upon the vertical distance between the present erosion surface and the original top or apex of the igneous mass.

[1] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, 1910.

OUTLINE OF REPORT.

The main physiographic divisions of Utah are (1) the Great Basin, occupying most of the western part of the State; (2) the Wasatch Mountains, flanking the Great Basin on the east for 200 miles southward from the Idaho boundary; (3) the Uinta Mountains, extending eastward from the Wasatch into Colorado; (4) the southwest margin of the Wyoming Basin, lying north of the Uinta and east of the Wasatch; and (5) the Plateau province, lying south and southwest of the Uinta.

Throughout the Mesozoic era a large part of the Basin Range province in Utah was above sea level and was undergoing erosion, the débris from which was largely deposited in the area now occupied by the Plateau and Uinta provinces. In post-Cretaceous time there was a general elevation of the entire region. The elevation was greatest along certain east-west belts forming the Uinta and Raft River ranges. Other uplifts that are less prominent physiographically though equally important structurally are the Tintic-Deep Creek and Beaver County uplifts. Contemporaneous with or soon after the general uplift there was a great outpouring of lavas over much of the Great Basin and part of the Plateau province. This volcanic action was followed by subsidence by which the Basin region was depressed below the Plateau region and was broken into blocks of general north-south trend, which were tilted at different angles and which formed the Basin ranges. The main effect of the movement in the Plateau region, where it was less pronounced, was to throw the more pliable Mesozoic sediments into folds with accompanying faults.

The sedimentary rocks of Utah range in age from pre-Cambrian to Recent. Pre-Cambrian rocks, mainly schist, shale, and quartzite, are exposed along the great east-west uplifts—the Uinta Mountains, Raft River Mountains, the Tintic-Deep Creek uplift—and adjacent to the great fault scarp which forms the west face of the Wasatch.

Resting unconformably on the pre-Cambrian rocks is a great series of Paleozoic quartzites, shales, and limestones ranging in age from Lower Cambrian to Permian. These beds show no marked angular unconformity, but they contain abundant evidence of periods of nondeposition and of erosion. These Paleozoic rocks form most of the Basin ranges, but they pass eastward beneath Mesozoic formations. Near the Colorado boundary, north of the Denver & Rio Grande Railroad, where the pre-Cambrian rocks are exposed, the Paleozoic formations are absent, having apparently wedged out toward the east.

Upon the Paleozoic formations lies a thick series of Mesozoic rocks, consisting principally of shales and sandstones but including some beds of limestone. These strata are exposed principally in the eastern part of the State, but they are found also at a few places in the Great Basin. They rest with little or no angular unconformity on the Paleozoic rocks; and within the Mesozoic strata there are no pronounced angular unconformities, though in the Mesozoic era, as in the Paleozoic, there were periods of nondeposition and of erosion.

Overlying the Mesozoic rocks in large areas south of the Uinta Mountains and in the Plateau region are Tertiary formations, which consist largely of sandstone and shale but include some limestone. At a few places in the Great Basin Tertiary sediments lying unconformably on the older rocks are exposed. Quaternary sediments occupy large areas in the Great Basin between the ranges.

Igneous rocks are of interest and importance in Utah, the extrusive rocks because of their great extent and the intrusive rocks, which are not relatively very abundant, because of their intimate relation to the ore deposits.

Extrusive rocks are most important in southern Utah, where they form a broad belt extending from the Nevada line eastward to the High Plateau and occupy large areas farther north in the Great Basin. A large part

of the lava is of intermediate composition, near latite, though rhyolites occur, and the latest flows are of basalt.

The intrusive rocks are largely confined to rather definite belts, the more important being the Park City, Little Cottonwood, and Bingham belt, the Tintic-Deep Creek belt, the Tushar, Mineral, Star, Beaver Lake, and San Francisco ranges belt, and the Iron Springs belt. In addition to these there are intrusions in the Grouse Creek, Raft River, and Pilot ranges and three centers of intrusion, the Henry, Abajo, and La Sal mountains, in the eastern part of the State.

In the western part of the State the large intrusive bodies are characteristically stocks; in the Plateau region they are laccoliths.

The composition of the intrusive rocks, like that of the extrusives, is prevailingly intermediate, near quartz monzonite and quartz diorite. In the stocks in the western part of the State the deeper exposed portions are the more siliceous, probably because of differentiation produced by the sinking of the ferromagnesian minerals, which were the earliest to form. In the laccoliths of the Plateau region there has been little such differentiation.

The age of many of the igneous bodies is not known from direct evidence. Those that have been determined are of post-Cretaceous age, probably most if not all of them are of Tertiary age.

The oldest large structural feature in the Paleozoic and later rocks is a general north-south folding, which is accompanied by overthrust faulting.

After the folding there were east-west uplifts, some of which were accompanied by intrusions. The Uinta and Raft River ranges represent such uplifts, and such structural features are associated with the intrusive belts farther south. The domes or swells and the broad uplifts that characterize the Plateau region may have been formed at the same time.

The youngest important structural features are the north-south faults that outline the Basin ranges and that also occur in the Plateau area.

The presence of metallic deposits in the mountains of Utah was known in the fifties, and a little lead ore was reduced to metal in a crude way by the Mormon settlers. Active prospecting began with the arrival of Gen. Connor's California volunteers, in 1862, and the first claim was located in Bingham Canyon in 1863. The production of placer gold began in 1865. Since 1870 there has been a steady and increasing output from lode mines, which to the close of 1917 had yielded a total of $816,827,182 and had paid dividends of $152,774,801.

The ore deposits of the State may be separated into two general classes—those that were deposited at the same time as their inclosing rock and those that were introduced after the formation of the rocks in which they are found. Those deposited with the inclosing rocks comprise no deposits of any importance except gold placers, and from these the yield has been relatively small. Those introduced later than the inclosing rocks may in turn be subdivided into two principal groups—those that show no close relation with igneous rocks and those that are believed to be genetically associated with igneous intrusion. Of those not associated with igneous rocks the most abundant representatives are the "red bed" or sandstone deposits of silver, copper, and uranium-vanadium, all of which are most commonly found in association with fossilized vegetable matter. The relations of certain of these deposits has led to the belief that they were formed later than most of the folds and faults and that these features were important factors in controlling the movement of the solutions that deposited the ores.

By far the greater number of deposits are so closely associated with igneous rocks that there can be little doubt that their origin is directly dependent on the igneous activity. They are most numerous and most extensive in the zones of greatest igneous activity in the western part of the State. They occur in the intrusive bodies, in the extrusive rocks, and in the sedimentary rocks adjacent to the intrusive bodies.

Deposits in the intrusive bodies are pegmatitic gold quartz veins, quartz-tourmaline-scheelite veins, copper quartz-tourmaline veins, quartz-pyrite-molybdenite veins, quartz copper veins, silver-lead quartz veins, gold quartz veins, silver-lead-copper quartz-barite veins, and magnetite-hematite veins. The close similarity of some of these veins to pegmatites and the gradation from one type to another has led to the belief that all the deposits in the

intrusive rocks were derived from material that separated from the crystallizing magma.

Deposits in the sedimentary rocks are subdivided into contact deposits and replacement deposits associated with fissures. The contact deposits include iron deposits, copper deposits, and gold deposits. Comparison of the changes that took place in the sediments while the contact deposits were being formed with the changes that took place in the intrusive rocks adjacent to the deposits leads to the conclusion that the solutions effecting the two sets of changes were so similar that it is reasonable to conclude that they had a common origin. The replacement deposits in sedimentary rocks associated with fissures include copper deposits, lead-silver deposits, zinc-lead-silver deposits, silver deposits, gold deposits, and quicksilver deposits. The transition and gradation from contact deposits to certain of the replacement deposits associated with fissures and among the different types of the replacement fissure deposits leave no doubt that all have a common origin.

Deposits in extrusive rocks are subdivided into silver-lead-zinc-copper deposits, gold-silver deposits, and alunite deposits. The relation of these deposits to those in the intrusive rocks and in the sediments indicate that all have a common origin.

The larger intrusive bodies of Utah are of two types, laccoliths and stocks. The laccoliths occur in the sandy and shaly sedimentary rocks in the southeastern part of the State and the stocks in the quartzites and limestones in the western part of the State. The stocks may be subdivided into those truncated by erosion near the apex and those truncated at a greater depth. Those truncated near the apex (apically truncated stocks) are monzonitic to dioritic in composition and those more deeply truncated are uniformly more siliceous, having the composition of granodiorite to granite.

Ore deposits associated with the laccoliths and the more deeply truncated stocks have proved to be of comparatively slight commercial importance, and those associated with the apically truncated stocks have proved to be of great value. It is believed that after intrusion the laccoliths were sealed off from their deep-seated source and that the amount of material already in them was too small and the differentiation on solidifying too incomplete to furnish large deposits. It is also believed that in the stocks the differentiation was greater at depth, and that the mobile constituents of the magma (water and gases carrying minerals in solution) rose toward the surface, whereas the heavier minerals that crystallized early sank to greater depths. When the mobile constituents reached a point where the magma was sufficiently solidified to fracture they were guided by the fractures or fissures and on reaching favorable physical and chemical environment began to deposit their metals. The more deeply truncated stocks are regarded as remnants from which the portion in which the metals were concentrated has been eroded.

It is regarded as possible that the connection of a magmatic body with the surface or zone of fracture at the time of intrusion may have been favorable to the rapid separation of the materials that formed the ore deposits.

Consideration of the relation of primary sulphates (barite, anhydrite, or alunite) in the ore deposits has led to the belief that they were formed directly from magmatic emanations. That they occur only in veins that were formed at relatively low temperature is believed to be due to the fact that the sulphate radicle (SO_3) is unstable at high temperature and that it forms rapidly and is stable only at relatively low temperature. The oxygen to form the sulphate is probably derived from oxygen compounds of iron and other elements. These compounds may be reduced to the lower state of oxidation or to sulphides.

The alteration of the ore deposits by surface agencies has had an important though variable effect on their composition. It has enhanced the value of nearly all the deposits by concentrating a certain metal, as copper, or by removing a part of one of the metals from a complex deposit, as zinc from lead-silver-zinc ore; or by changing the character of the ore during its oxidation so as to render it more amenable to metallurgic treatment, as in some of the gold and silver deposits. In general, lead, silver, and gold migrated but little during the process of oxidation, and their ores were improved by the removal of other constituents. Copper and zinc, on the other hand, migrated readily and under favorable conditions were reprecipitated in a concentrated form, producing valuable deposits.

THE ORE DEPOSITS OF UTAH.

By B. S. Butler.

PART I.—GENERAL FEATURES.

INTRODUCTION.

FIELD WORK AND AUTHORSHIP.

The senior author, B. S. Butler, began field work on the ore deposits of Utah in the summer of 1908 by making a detailed study of the ore deposits of the San Francisco and adjacent districts. The results of this work were published as Professional Paper 80 of the United States Geological Survey. Later he made a reconnaissance of the other districts in southern Utah, and eventually of the districts farther north, including the Deep Creek, Fish Springs, Dugway, Silver Islet, Grouse Creek, Raft River, Promontory, and Oquirrh ranges and, together with G. F. Loughlin, of the Cottonwood-American Fork area. In order to gain a personal knowledge of the geology and to make observations on later developments, visits were made to districts that had previously been studied in detail by other writers. In 1913 the senior author, in company with F. L. Hess, examined deposits in the Uinta Mountains and in the vicinity of the La Sal and Henry mountains. In 1914, in company with W. L. Whitehead, he spent two months in a further study of the geology and ore deposits in the Plateau region.

The junior author, G. F. Loughlin, began work in the Tintic district in 1911 in collaboration with Waldemar Lindgren. The results of this work are presented in Professional Paper 107. Reconnaissance studies were afterward made by him of the districts between the Tintic and Thomas ranges, of the Leamington district, and of districts in the Wasatch Range.

Several of the mining districts of the State have been studied in detail by other writers, and their reports have been published. The general results of these studies have been embodied in this report. The more important reports are those on the Mercur district, by J. E. Spurr and S. F. Emmons; the Bingham district, by J. M. Boutwell, Arthur Keith, and S. F. Emmons; the Park City district, by J. M. Boutwell and L. H. Woolsey; the Iron Springs district, by C. K. Leith and E. C. Harder; and the Tintic district, described first by G. W. Tower and G. O. Smith and later by Waldemar Lindgren and G. F. Loughlin.

In 1916 and 1917 detailed work was carried on in the Cottonwood-American Fork region. This work was interrupted by the war, but some of the results are incorporated in this paper.

The general section of this report was prepared by B. S. Butler, and the reports on the several districts by the writers indicated in the body of the report. The historical and statistical data, both for the general section and for the individual districts, were collected by V. C. Heikes, of the Salt Lake City office of the Geological Survey.

SCOPE OF THE REPORT.

There are several well-defined mineral belts within the State, and particular attention has been given to the relation of the ore deposits within these belts. Individual districts have been described in as much detail as the conditions of study have warranted. In some districts there was little or no activity at the times of visit and very meager opportunity for studies below the surface, whereas in other districts there were abundant opportunities for such studies. No attempt has been made to describe individual mines except as illustrations of a particular type of deposit. The mines in several of the larger districts have already been described in reports published by the Geological Survey, and those in other districts

will doubtless be described as opportunity affords.

ACKNOWLEDGMENTS.

For a large proportion of the data contained in the report the writers are indebted to other workers. From its earliest exploration the region has been one of unusual interest to geologists, and studies made within it have resulted in reports that have become classic. Perhaps no area of equal size in the West has been so productive of geologic literature; even to enumerate the papers requires many pages. (See Bibliography, pp. 38–57.) It is hardly necessary to say that the accumulation of such data was a condition precedent to the preparation of the present report, a considerable part of which consists of an attempt to correlate systematically the data relative to ore deposits contained in the papers previously published.

The authors are deeply indebted to the mining men of the State, who have freely furnished information and presented and discussed relations and ideas which have not appeared in print and for which it is difficult to give proper credit, though an attempt to do so has been made. The authors feel that they will be pardoned if in this general acknowledgment they do not mention by name those who have extended courtesies during the long period that field work was in progress. To those who are familiar with the mining districts of the State it is unnecessary to say that the traveler in them is everywhere most cordially received. The pleasant recollections of trips to remote and in many respects uninviting places are due in no small part to the hospitality generously extended by the residents, which remains fresh in memory after the discomforts have long been forgotten.

The authors also wish to express their indebtedness to other members of the Survey for the determination of fossils, for chemical and mineralogic determinations, and for suggestions and criticism bearing on the geologic problems involved. It is a pleasure especially to acknowledge the helpful suggestions and criticisms of Mr. Waldemar Lindgren, under whose direction this work was begun, and of Mr. F. L. Ransome, under whose supervision it was completed.

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GEOGRAPHY.

As Utah lies in both the Plateau and the Great Basin provinces of the Cordilleran region it possesses a great variety of geographic and climatic features. The differences in the latitude and the altitude of the different sections result in temperature differences, ranging from semitropical to semifrigid and in equally marked differences in precipitation. The topographic and climatic conditions have exerted a marked influence on the development of the industries of the State.

TOPOGRAPHY.

RELIEF.

The most important physiographic frontier in Utah sweeps as a curve of gentle westward concavity from about the middle of the northern boundary to the southwest corner of the State. The part of Utah lying west of this line is almost entirely within the Great Basin; the larger part of the State which lies to the east belongs to the Plateau province as defined by Powell, but as some parts of it have not the plateau character it may be best designated, as a whole, the eastern section.

The typical features of the Great Basin, a vast region having no outlet to the sea and characterized topographically by the alternation of relatively broad, coalescing desert valleys with relatively narrow mountain ranges of general north-south trend, are well epitomized in western Utah. The Raft River Mountains, in the northwest corner of the State, are exceptional in their east-west elongation and irregular plan, but these lie on the very border of the province, the drainage of their northern flank being tributary to Snake River. The other ranges of western Utah are typical in trend and form. They rise like islands and peninsulas above a desert floor, large parts of which appear almost as level as a sea. The broadest open portion of this surface, the Great Salt Lake Desert, is one of the most extensive arid plains in the whole Great Basin, as Great Salt Lake is by far the largest of the saline lakes in which the rivers of that province generally terminate.

Despite the apparent flatness of the desert floor, its elevation ranges from about 4,300

feet at the shore of Great Salt Lake to nearly 6,000 feet at the head of Escalante Desert. It rises gradually southward as a whole, and the border of each desert valley slopes gently upward toward the bordering mountains. The broad valley floors are but slightly intrenched by the few streams that reach them; their borders are somewhat diversified, however, by the erosive work of mountain streams, and in places by the abandoned shore features of Lake Bonneville, of which Great Salt Lake is a shrunken remnant. Some of the isolated mountain ridges rise 4,000 to 5,000 feet above the general surface of the desert, and some of their highest peaks are more than 12,000 feet above sea level. Their topography is necessarily rugged because of their relatively high and narrow form.

The eastern section of Utah has far less unity of character than the western or Great Basin section. Powell,[1] indeed, assigned the eastern section as a whole to the Plateau province, and this assignment may in a measure be justified. Viewed in a very broad way, the region is a rolling upland surface; it is high above sea level, and, although a large part of its surface is lower than the Escalante Desert, all of its western margin stands above the desert floor of the Great Basin.

The physiographic unity of the region is, however, interrupted in the northeastern part of the State by two great mountain ranges, the Wasatch and the Uinta, which can not be neglected in any but the broadest classification. The Wasatch Mountains, which rise directly from the eastern limit of the Great Basin, extend from southern Idaho to the town of Nephi, near the center of Utah. The Uinta Range nearly meets the Wasatch about southeast of Salt Lake City and extends eastward into Wyoming and Colorado, the axes of the two ranges running nearly at right angles to each other. The classification adopted recently by the physiographic committee includes both the Wasatch and Uinta ranges in the northern Rocky Mountain province, assigns the tract in the angle northeast of them to the Wyoming Basin—a subprovince of the Rocky Mountains—and leaves to the Plateau province only that part of the eastern section of Utah that lies south of the Uinta Range. According to this scheme the Plateau province described by Powell is divided by a physiographic boundary of the first rank—the common limit of the northern Rockies and of the Plateau region in the narrower sense.

A mental picture of the eastern section of Utah is most easily formed by bearing in mind these four main subdivisions—the Plateau region at the south, the Wasatch Range along the northwest border, the Uinta Range extending eastward from the Wasatch, and the Wyoming Basin, overlapping slightly the northeastern reentrant of the State boundary. The relief of each of these subdivisions may now be briefly characterized.

The Plateau region is, broadly speaking, a gently rolling surface deeply intrenched by streams, being, unlike the desert floor of the Great Basin, diversified chiefly by depressions rather than by prominences; but a few clusters of knoblike mountains—the Henry, Abajo, and La Sal groups and Navajo Mountain—are superposed upon the plateau surface. The elevation of this surface ranges from more than 9,000 to about 3,000 feet; it decreases on the whole, though by no means uniformly, southward and southwestward from the base of the Uinta Mountains. The deepest intrenchment has been effected near the southern boundary of the State by Colorado River, the bottom of whose canyon is there about 4,000 feet below the top of the neighboring Kaiparowits Plateau. The walls of this canyon and of others in the nearly horizontal strata that underlie most of the region tend to simulate the well-known style of the Grand Canyon of Arizona, with its characteristic alternation of talus, cliff, and terrace, and much of the upland surface is diversified by "badland" topography and other picturesque details. The superposed mountains, which differ from the plateaus in structure and in sculpture, attain elevations of about 11,000 feet above sea level, or 5,000 feet above the surrounding plateau surfaces.

The Uinta Mountains are simpler than most ranges in form and structure, having been produced principally by uplift along an east and west axis in such manner that their typical cross section is essentially a flat-topped but rather steep-sided arch. The Uinta was regarded by Powell as a plateau, and structurally it is one, but its great height and deep dissection justify its usual designation as a mountain range. In its axial part broad glaciated amphi-

[1] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains: U. S. Geol. and Geog. Survey Terr., 2d div., 1876.

theaters and canyons alternate with flat or acute ridges and summits, many of which are more than 10,000 feet and the highest more than 13,000 feet above sea level. The range has a well-defined western terminus at Kamas Prairie but is not very sharply delimited on the north and south from the Wyoming Basin and the Plateau region.

The Wyoming Basin, of which Utah contains but a very small part and with which this report is little concerned, may be dismissed with the statement that it bears some general resemblance to the Plateau region.

The Wasatch Mountains are far more heterogeneous and complex than the Uinta Mountains and are divisible into three sections of markedly differing character.

The southern Wasatch extends from the southern terminus of the range, at Nephi, to the canyon of the American Fork. It consists of a curving row of lofty peaks and ridges which rise abruptly both from the desert floor on the west and from the plateau surface on the east, and which are separated from each other by canyons that head far eastward. The highest mountain of the southern Wasatch is Mount Timpanogos, which stands 11,957 feet above sea level and more than 7,000 feet above the town of Pleasant Grove, which lies at its base.

The middle Wasatch extends from the American Fork to Weber River. Unlike the southern section, but like most other mountain ranges, it has a persistent main divide, namely, the watershed that parts the tributaries of Weber and Provo rivers from the short streams that reach the Great Basin more directly. The loftiest part of this section—that lying south of Salt Lake City—resembles the southern Wasatch in that its highest peaks lie west of the main divide and rise abruptly from the desert; but these peaks do not form a prominent row and are connected with the divide by nearly level spurs. The highest summits are about 11,000 feet high. The east side of this broad, massive, rugged portion of the range descends about 3,000 feet or more to the prairie zone that separates it from the Uinta. North of Salt Lake City the divide lies farther west, is considerably lower than to the south, and is really nothing more than the western edge of the deeply dissected Wyoming Basin.

The northern Wasatch, which extends from Weber River into southern Idaho, has two branches that are separated by the broad Logan Valley. The western branch, which may be called the northern Wasatch proper, is a narrow ridge that is about 10,000 feet in maximum height but becomes lower and less continuous northward. The eastern branch, generally called the Bear River Range or Plateau, maintains more uniformly this level of about 10,000 feet; it merges rather gradually on the east with the dissected upland margin of the Wyoming Basin.

DRAINAGE.

The extreme northwestern part of Utah drains by way of Raft River to Snake River. The drainage of the remainder of the State is divided almost equally, in the areal sense, between the Great Basin and Colorado River, for much of the larger eastern section of the State drains into the western or Great Basin section, whose drainage, by definition, is self-contained. The course of the divide between these two main drainage areas is extremely tortuous.

The distribution of the streams in the eastern section shows remarkable disregard of physiographic boundaries. Most of the section is drained by Colorado River, of which Green River is the main branch and, in all but name, the upper headwater portion. Green River crosses the eastern Uinta Mountains in Colorado by way of a profound canyon, through which it drains a large part of the Wyoming Basin. Its tributaries also drain the greater part of both flanks of the Uinta Range. Most of the Plateau region is drained by the Colorado through Green River and other tributaries, the largest of which are Grand, Frémont, San Juan, and Virgin rivers. The longest stream that flows from the eastern section of Utah to the Great Basin is Bear River, which rises in the southwestern corner of the Wyoming Basin, flows northward through Bear Lake into Idaho, turns abruptly southward into Utah, and finally empties into Great Salt Lake. Other streams that flow from the Wasatch Mountains or the plateaus to the Great Basin are the Ogden, Weber, Provo, Spanish Fork, and Sevier. All these rivers but the last cut across the Wasatch Range, whose east flank is drained by them, its run-off thus being wholly tributary to the Great Basin.

Only two streams not already mentioned flow far on the floor of the Great Basin—the Jordan runs from Utah Lake to Great Salt Lake; the Sevier sinks in the Sevier Desert and Lake. A few other small streams flow into Great Salt Lake. Few of those that rise in the basin ranges persist far into the desert. Many of the lower ranges give rise to no perennial streams, their only permanent water supply being derived from springs.

CLIMATE.

The variation in climate of different parts of Utah depends chiefly on the altitude and in less degree on the latitude. In the Great Basin region there are no great extremes of either heat or cold. In the lower valleys the summer temperature is sometimes disagreeably warm but in the mountains it is usually moderate. The cold in winter is rarely extreme. In the higher portions of the State, as the Uinta and Wasatch mountains and portions of the Plateau region, the summers are short and cool and the winters are frequently extremely cold and long. In the lower areas, in the southern part of the State, notably along Virgin River (Dixie), the summers are hot and the winters are mild, snow rarely accumulating.

Mean temperature (°F.) at stations in Utah to end of 1918.

Western Utah.

Station.	Length of record.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
	Years.													
Beaver	10	29.1	30.1	39.2	45.3	60.8	60.8	67.8	67.1	57.6	47.6	38.7	27.3	47.6
Black Rock	14	26.1	31.8	40.6	48.1	55.2	62.8	70.6	68.9	59.2	48.0	38.5	26.4	47.6
Blue Creek	13	25.4	28.8	37.9	50.8	60.9	70.3	78.9	77.3	63.5	50.0	39.8	27.5	50.9
Cedar City	12	32.2	35.1	41.8	48.4	55.4	65.9	72.9	70.4	61.8	50.6	41.4	31.1	50.6
Corinne	28	24.4	29.8	39.8	50.1	59.4	69.7	78.0	74.0	64.6	50.8	37.4	28.3	50.5
Deseret	23	26.6	31.2	40.6	48.2	55.8	65.0	72.5	71.4	60.6	49.2	37.6	25.9	48.7
Elberta	15	27.9	31.4	40.7	50.1	56.8	67.0	74.4	73.6	62.7	50.5	39.0	28.1	50.2
Farmington	17	29.1	33.0	40.7	48.8	56.2	64.7	72.8	70.8	59.9	49.5	39.9	30.5	49.7
Fillmore	26	30.5	34.1	41.7	50.0	57.8	67.6	75.2	74.4	64.8	52.6	41.8	29.8	51.7
Frisco	16	31.9	33.1	38.8	46.5	54.9	67.7	73.5	67.0	62.6	49.3	39.8	31.0	49.7
Garrison	12	27.8	32.6	40.3	48.4	55.2	64.2	72.0	70.5	61.6	48.2	39.7	29.1	49.1
Government Creek	17	27.0	30.4	38.3	46.6	53.1	63.0	72.8	71.9	61.0	49.0	38.3	27.6	48.2
Heber	25	20.9	23.9	33.9	44.2	51.5	59.1	65.7	64.5	55.2	45.3	35.2	22.4	43.5
Henefer	18	22.1	25.8	35.2	44.1	50.8	58.2	65.1	63.9	54.7	45.2	35.0	23.6	43.6
Ibapah	12	24.7	27.9	35.6	44.7	48.5	56.7	65.8	65.9	56.6	44.7	34.5	24.4	44.2
Kelton	26	22.0	27.2	38.4	47.3	56.2	66.4	74.9	71.9	59.7	47.4	34.9	25.5	47.6
Laketown	17	21.8	21.7	29.0	41.1	48.9	56.7	64.6	63.2	53.7	43.5	33.3	24.4	41.8
Levan	27	24.5	28.6	37.1	46.4	52.5	63.6	71.4	69.8	60.0	47.5	36.9	25.5	47.0
Logan	26	24.1	26.7	36.0	47.6	54.4	63.2	71.7	70.8	61.2	49.8	37.8	25.6	47.4
Lucin	11	22.5	29.1	39.9	47.2	53.3	62.1	71.3	70.5	59.8	46.0	35.3	24.3	46.8
Manti	22	24.8	28.3	37.8	46.1	54.5	63.3	69.4	67.8	59.0	47.8	37.4	25.3	46.8
Marysvale	16	28.2	31.0	37.7	45.0	51.0	59.7	66.0	65.0	58.0	47.2	37.0	25.0	45.9
Modena	17	27.3	30.9	38.5	45.9	52.8	63.0	74.5	69.2	59.5	48.3	37.6	27.5	47.9
Morgan	12	22.9	26.7	35.9	45.6	51.6	59.3	66.4	65.7	56.3	46.0	36.3	23.2	44.8
Mount Pleasant	15	27.7	31.0	38.1	47.5	54.9	63.9	71.7	71.4	61.0	49.4	38.6	26.9	48.5
Ogden	27	29.3	32.1	40.6	51.4	59.1	68.8	76.5	75.4	63.0	51.1	40.1	30.6	51.5
Park City	15	23.0	25.8	30.3	39.8	48.8	56.9	63.7	62.0	55.2	45.3	34.4	24.6	42.5
Parowan	27	29.0	31.9	39.3	47.1	51.6	64.1	70.5	66.6	60.1	49.4	40.8	28.8	48.5
Pinto	19	26.6	30.1	35.5	43.0	48.9	58.5	66.0	64.3	53.2	44.3	36.4	26.0	44.4
Provo	24	26.9	31.4	39.2	48.4	56.6	64.2	72.2	70.3	60.4	49.0	39.4	28.5	48.9
Richfield	23	26.8	32.0	40.1	47.8	54.9	63.4	70.3	68.1	58.9	48.2	37.7	27.6	48.0
Saltair	14	28.0	32.7	40.9	50.1	57.0	66.4	74.9	73.7	63.3	50.6	39.7	29.9	50.6
Salt Lake	44	29.2	33.4	41.6	50.0	57.4	67.0	76.0	74.6	64.4	52.4	40.9	31.0	51.6
Scipio	23	27.3	31.3	38.6	46.8	53.2	62.7	69.7	68.4	59.2	47.7	37.8	26.6	47.4
Snowville	24	22.7	27.3	35.8	45.5	53.1	60.2	68.4	67.2	57.6	46.9	36.2	25.3	45.5
Soldier Summit	13	17.7	21.8	28.4	39.5	46.6	53.5	60.5	60.8	51.1	41.2	29.0	17.5	39.0
Thistle	21	24.2	29.4	36.9	47.0	53.0	61.6	69.4	68.4	57.9	47.8	36.5	75.6	46.5
Tooele	22	29.2	32.6	39.8	48.7	55.4	65.2	73.0	72.5	62.8	50.3	39.7	30.6	50.0
Woodruff	14	15.3	16.7	27.8	40.3	46.9	55.0	60.7	59.6	51.0	40.6	30.2	19.1	38.6

Mean temperature (° F.) at stations in Utah to end of 1918—Continued.

Eastern Utah.

Station.	Length of record.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
Alton	15	21.6	27.4	32.5	41.9	48.0	56.1	62.0	61.8	54.8	45.8	36.5	26.5	43.1
Aneth	10	30.4	37.8	46.2	54.7	63.1	72.2	78.1	77.3	67.5	50.5	42.6	31.1	54.3
Blanding	11	27.1	32.9	40.5	48.1	53.9	65.0	71.0	70.2	61.2	51.2	40.2	28.2	49.1
Castle Dale	18	18.9	25.7	37.4	46.1	53.9	63.2	69.1	68.1	58.8	47.1	36.9	23.3	45.6
Cisco	12	23.2	29.7	42.0	53.1	62.0	72.0	79.3	77.3	67.2	52.2	39.3	25.6	51.9
Duchesne	12	16.1	21.6	35.4	46.1	52.1	60.5	68.0	66.8	57.9	46.1	33.1	18.9	43.8
Emery	16	24.3	29.1	37.4	44.9	51.8	59.9	65.0	64.9	56.9	46.9	37.9	27.7	45.3
Escalante	12	26.4	32.7	40.9	48.2	55.0	64.2	69.2	67.8	59.9	49.9	39.4	28.5	48.8
Fort Duchesne	26	13.5	18.4	34.3	45.5	53.5	62.0	68.2	67.1	58.0	44.8	32.6	16.3	43.0
Giles	12	25.1	31.2	42.5	52.2	61.8	69.7	77.2	74.6	64.6	50.9	38.0	24.9	51.1
Green River	17	23.2	33.3	45.2	54.0	62.1	73.5	79.0	76.7	65.6	52.0	39.1	24.4	52.1
Hite	14	35.7	42.4	51.1	59.2	68.2	77.7	84.2	82.8	72.5	59.7	47.5	35.2	59.7
La Sal	14	25.2	28.4	35.4	44.5	51.4	61.0	67.1	66.0	57.2	46.2	37.4	24.8	45.4
Loa	19	24.6	24.1	32.2	40.5	48.7	58.6	65.9	62.9	53.0	41.3	31.1	20.9	42.0
Moab	28	28.8	36.2	43.1	55.5	63.8	72.0	77.9	75.5	66.2	55.3	41.5	30.3	53.9
St. George	27	37.5	42.0	49.4	57.4	66.4	75.9	82.1	80.6	71.1	59.1	45.8	37.6	58.7
Springdale	12	38.2	44.9	50.2	55.5	63.4	75.4	80.5	78.2	71.1	61.9	49.5	40.9	59.1
Tropic	20	27.4	30.4	38.2	44.8	52.1	61.3	67.1	64.9	57.9	48.1	38.2	28.3	46.4
Vernal	19	18.8	23.5	36.3	48.9	55.6	65.8	71.0	69.1	59.4	47.1	36.0	20.2	46.1

Highest and lowest temperatures (° F.) at stations in Utah to end of 1918.

Western Utah.

Station.	Length of record.	January.		February.		March.		April.		May.		June.		July.		August.		September.		October.		November.		December.		Annual.	
		Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.	Highest.	Lowest.
	Yrs.																										
Beaver	12	66	−22	75	−21	86	− 6	79	12	98	10	102	23	97	35	101	32	89	14	87	6	80	−10	70	−17	102	−22
Black Rock	15	60	−33	80	−26	78	− 1	90	10	99	18	106	25	105	30	102	29	96	17	90	5	79	− 7	64	−32	106	−33
Cedar City	13	64	−18	63	−17	74	3	80	14	95	19	98	33	97	43	98	37	91	20	85	14	74	4	67	− 5	98	−18
Corinne	28	60	−22	67	−16	76	− 5	89	9	99	20	105	27	109	38	110	31	102	23	95	13	76	− 6	59	−13	110	−22
Deseret	24	60	−28	71	−28	80	− 9	87	7	91	21	106	22	104	32	104	26	98	21	89	16	79	− 4	67	−17	106	−28
Elberta	15	60	−12	64	−15	76	3	86	12	90	23	104	32	100	34	102	34	95	27	86	18	76	0	62	−10	104	−15
Farmington	18	58	−10	62	− 9	76	10	84	18	92	26	101	30	100	37	99	36	90	27	85	19	70	1	59	− 5	101	−18
Fillmore	27	74	−23	74	−17	80	− 2	92	7	103	19	105	22	115	32	109	32	104	9	95	13	86	−11	67	−14	115	−23
Frisco	16	68	− 7	63	−17	72	2	84	11	97	16	100	29	103	33	100	37	93	27	84	10	69	− 4	61	− 9	101	−17
Garrison	11	62	−17	68	−22	75	5	86	10	94	22	97	27	100	33	98	32	92	17	91	2	78	− 5	67	−19	100	−22
Government Creek	18	59	−17	63	−22	75	− 2	84	9	95	21	99	28	101	34	102	37	95	23	85	14	71	− 2	60	− 9	102	−22
Heber	26	60	−30	58	−38	70	−14	83	0	91	15	100	25	100	28	96	24	92	18	83	6	70	−14	60	−28	100	−38
Henefer	19	57	−28	60	−39	73	18	83	1	92	18	101	25	98	29	95	23	92	17	89	4	72	−19	63	−27	101	−39
Ibapah	13	67	−29	64	−32	74	− 8	81	0	88	12	98	22	98	28	97	26	93	14	84	4	73	− 9	67	−25	98	−32
Kelton	27	60	−25	56	−27	72	− 5	80	13	92	13	106	28	114	37	107	30	94	12	86	6	74	− 8	61	−22	114	−27
Laketown	18	50	−20	55	−36	66	−22	78	2	84	19	94	27	106	31	93	25	89	22	83	9	67	− 9	58	−11	103	−36
Lehi	9	58	−23	58	−12	79	− 4	85	13	96	24	102	31	100	38	100	35	91	26	87	12	75	0	54	−17	102	−23
Lemay	8	63	−20	78	− 5	76	10	83	10	96	27	105	30	110	46	107	40	97	28	84	10	68	4	58	−12	110	−20
Levan	26	57	−26	59	−23	74	1	88	12	91	20	98	29	101	34	98	33	91	21	85	14	74	−10	59	−17	101	−23
Logan	27	54	−19	58	−19	73	− 6	90	13	92	16	98	28	101	37	99	35	93	26	85	16	73	−11	57	−15	101	−19
Lucin	11	59	−23	79	−10	72	0	88	8	95	18	102	16	105	29	100	26	95	17	80	7	72	− 1	62	−13	105	−23
Manti	22	60	−22	70	−25	82	− 4	88	8	98	18	108	27	108	32	110	27	100	20	90	11	74	− 8	62	−18	110	−25
Marysvale	15	62	−22	67	−33	75	− 5	84	11	96	17	90	26	99	29	95	31	91	20	88	7	75	−11	66	−21	99	−33
Midlake	8	49	7	48	10	63	17	78	26	88	32	91	35	92	55	90	55	82	42	73	25	63	17	56	13	92	7
Milford	11	60	−25	65	−15	80	− 4	82	11	98	20	102	20	102	37	99	30	96	22	86	9	75	− 8	68	−25	102	−25
Modena	18	64	−19	66	−17	72	− 1	80	14	92	21	99	30	98	31	97	41	92	24	84	13	74	− 7	65	−24	99	−24
Morgan	12	59	−20	61	−31	71	−10	81	1	89	19	98	28	98	32	96	28	92	21	85	4	73	−14	60	−25	98	−31
Moroni	9	54	−17	53	−18	73	0	79	9	85	21	100	28	97	42	96	39	89	25	86	11	73	− 9	61	−17	100	−18
Mount Pleasant	15	68	−12	64	−23	75	3	95	12	99	19	100	30	110	33	111	34	99	20	85	14	73	0	60	−15	111	−23
Oak City	10	62	−12	64	− 5	80	3	87	18	100	27	102	29	103	42	104	35	98	29	92	12	72	3	68	−11	101	−12
Ogden	28	57	−13	64	−16	70	−10	85	16	92	26	101	30	104	36	101	36	96	26	88	18	74	− 2	60	− 4	104	−16
Park City	16	64	−28	64	−20	71	−23	86	− 4	91	12	101	11	99	21	92	26	91	8	82	− 5	77	−11	56	−22	101	−28
Parowan	28	63	−17	66	−18	82	− 2	90	7	92	20	103	27	102	29	102	33	95	23	89	15	76	− 7	67	−14	102	−18
Pinto	20	65	−27	63	−20	72	−13	79	−3	93	11	95	24	100	26	95	30	91	20	95	7	72	−13	70	−27	100	−27
Provo	20	66	.....	69	.....	79	.....	93	.....	101	...	110	...	105	...	105	...	96	...	93	.....	79	.....	63	.....	110	.....
Richfield	21	62	−24	70	−26	81	− 5	90	5	103	19	100	20	102	30	99	22	98	12	89	10	79	− 6	66	−17	103	−26
Saltair	15	62	− 3	68	0	71	11	81	18	84	30	94	36	96	48	94	45	91	32	82	21	70	7	60	0	96	− 3
Salt Lake City	45	60	−20	68	−13	77	0	85	18	93	25	101	32	102	43	101	44	93	29	88	22	74	− 2	61	−10	102	−20
Scipio	24	69	−33	70	−39	78	− 4	86	7	94	13	102	24	106	30	101	26	95	19	88	6	77	−23	67	−27	106	−39
Snowville	25	57	−26	64	−30	70	−12	81	2	90	16	102	21	102	30	106	27	93	11	87	6	70	−12	58	−18	102	−30
Soldier Summit	13	49	−27	62	−20	66	−15	86	2	91	12	97	18	100	23	100	22	88	15	85	2	64	−20	60	−20	100	−27
Spanish Fork	9	74	−16	64	− 5	76	1	88	18	92	20	98	31	101	42	101	41	96	31	86	11	87	0	64	− 5	101	−16
Standrod	11	58	−16	56	−10	69	− 2	90	12	84	15	93	27	92	33	92	33	87	22	78	12	68	0	59	− 5	93	−16
Thistle	22	69	−33	70	−25	78	−18	87	8	96	19	105	23	112	25	105	25	100	17	98	2	90	−11	65	−25	112	−35
Tooele	23	60	−10	64	− 9	76	5	87	16	90	22	98	31	100	35	102	37	96	28	83	21	80	− 4	60	− 6	102	−10
Woodruff	14	55	−38	65	−50	67	−32	80	0	86	6	93	21	102	21	115	20	111	8	83	5	67	−30	67	−30	115	−50

Highest and lowest temperatures (° F.) at stations in Utah to end of 1918—Continued.

Eastern Utah.

Station.	Length of record.	January. Highest.	January. Lowest.	February. Highest.	February. Lowest.	March. Highest.	March. Lowest.	April. Highest.	April. Lowest.	May. Highest.	May. Lowest.	June. Highest.	June. Lowest.	July. Highest.	July. Lowest.	August. Highest.	August. Lowest.	September. Highest.	September. Lowest.	October. Highest.	October. Lowest.	November. Highest.	November. Lowest.	December. Highest.	December. Lowest.	Annual. Highest.	Annual. Lowest.
	Yrs.																										
Alton	10	63	−20	62	−20	67	−10	78	5	87	5	94	25	93	25	93	31	88	18	81	3	70	−9	68	−19	94	−20
Aneth	10	63	−29	77	2	83	14	86	19	93	31	105	38	104	45	106	42	100	28	88	22	74	10	67	−2	106	−29
Blanding	12	62	−15	71	−9	86	9	88	10	91	15	110	28	109	42	106	40	100	20	99	12	74	6	61	−9	110	−15
Castle Dale	19	62	−32	63	−34	78	−2	89	5	94	14	101	24	104	29	103	30	95	19	84	4	83	−9	63	−35	104	−35
Cisco	13	66	−26	71	−23	90	8	88	12	100	27	109	32	108	45	107	45	100	29	88	16	77	5	64	−18	109	−26
Duchesne	13	54	−26	58	−32	74	−12	83	10	92	18	95	27	97	35	94	26	90	10	79	4	66	−1	58	−34	97	−34
East Portal	7	55	−50	42	−43	55	−37	66	−19	75	6	86	11	84	24	83	25	80	10	77	0	62	−22	51	−36	86	−50
Emery	18	60	−12	67	−20	72	1	82	9	87	12	97	25	99	32	95	34	91	22	82	12	75	0	67	−13	99	−20
Escalante	13	61	−17	84	−11	80	10	83	13	92	25	98	31	98	38	97	32	90	22	87	16	72	1	62	−15	98	−17
Fort Duchesne	28	59	−34	60	−36	79	−14	86	4	95	21	101	21	104	34	101	31	94	17	85	4	76	−11	61	−27	104	−36
Giles	12	59	−21	70	−18	84	5	95	8	100	26	110	32	111	39	106	39	99	25	89	11	73	−5	64	−11	111	−21
Green River	17	70	−27	86	−23	83	10	95	15	101	25	109	34	112	41	110	39	103	27	97	12	81	1	74	−23	112	−27
Hanksville	7	65	−26	75	−18	78	7	88	11	92	25	106	34	112	44	108	40	102	31	90	10	74	−2	62	−19	112	−26
Hite	14	66	1	81	6	86	18	94	28	104	35	111	40	115	44	110	51	104	39	91	20	76	19	76	−1	115	−1
Kanab	9	62	−15	70	−8	85	1	87	8	101	16	101	23	105	39	101	35	95	24	89	9	79	10	66	−11	105	−15
La Sal	14	56	−22	64	−15	70	−3	76	12	85	19	94	25	94	34	93	37	86	19	80	0	81	−1	76	−11	94	−22
Loa	18	70	−30	70	−35	72	−15	79	0	92	10	98	19	110	19	100	23	90	10	81	−1	76	−18	60	−26	110	−35
Manila	7	62	−32	59	−31	68	−14	71	−6	83	15	95	25	95	30	95	33	88	19	82	−3	73	−20	64	−28	95	−32
Moab	28	65	−18	78	−13	88	8	97	16	102	27	107	36	109	43	107	41	101	29	90	18	82	9	68	−10	109	−18
Monticello	10	57	−10	80	−11	81	2	80	11	82	19	97	30	92	35	98	40	89	25	80	13	70	−2	56	−10	98	−11
St. George	28	71	−1	81	1	87	12	98	18	108	20	116	35	115	41	113	43	104	25	99	20	84	4	71	0	116	−1
Scofield	10	56	−41	49	−35	64	−27	74	−8	88	10	91	14	98	24	94	24	83	12	74	−9	67	−20	56	−37	98	−41
Springdale	13	72	−11	89	1	89	12	92	26	100	31	106	38	109	41	110	35	103	34	95	25	90	10	81	3	110	−11
Tropic	20	67	−20	67	−32	74	0	84	6	96	13	100	20	101	32	101	30	100	11	84	10	72	−9	76	−15	101	−32
Vernal	20	56	−21	60	−25	79	−5	85	7	105	19	99	24	102	34	99	34	94	20	86	11	71	−5	55	−18	106	−25
Wellington	8	50	−15	68	−23	87	−4	90	9	91	16	100	30	102	32	101	31	97	21	84	7	78	−7	65	−30	102	−30

The precipitation, like the temperature, is very different in different sections of the State, and, like the temperature, is largely dependent on altitude, being greatest in the higher portions. Thus the Uinta and Wasatch ranges and portions of the High Plateau have rather abundant rain and snowfall, whereas the lower lands of the western part of the State have much less. In the higher areas much of the precipitation comes as snow, which does not completely melt till late in spring or in summer and thus tends to equalize the flow of the streams.

The following table and diagram (fig. 1, p. 64), taken from the reports of the United States Weather Bureau, show the precipitation in different sections of the State:

Average monthly and annual precipitation (in inches) at Weather Bureau stations in Utah.

Station.	County.	Elevation (feet).	Years.	January.	February.	March.	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
Alpine	Utah	4,900	1896–1918	1.70	1.80	2.12	1.90	2.26	0.81	0.69	0.96	1.22	1.60	1.27	1.41	18.45
Aneth	San Juan	4,800	1900–1913	.49	.67	.83	.41	.20	.26	.74	.76	1.08	.55	.60	.42	7.10
Annabella	Sevier	5,250	1908–1910	.71	.75	.63	.58	.66	.20	.92	2.04	.82	.80	.69	1.13	9.93
Alton	Kane	7,000	1902–1918	3.34	2.62	4.18	1.30	.97	.47	2.08	1.99	1.83	1.52	1.67	1.65	23.62
Beaver	Beaver	6,000	1889–1918	.99	1.03	1.21	.91	1.04	.42	1.54	1.56	1.40	.98	.80	1.20	13.08
Belknap Ranger station	do.	6,800	1914–1916	1.04	.98	.36	1.80	1.19	1.12	1.94	.42	.92	.75	.66	.34	11.32
Benmore	Tooele	5,500	1912–1918	1.63	1.43	1.67	1.54	1.62	1.18	1.09	.69	1.12	1.22	.96	.86	15.01
Black Rock	Millard	4,872	1901–1918	.73	.97	.92	.98	.93	.36	.70	.58	.98	1.06	.66	.40	9.38
Blacksmiths Fork	Cache	5,500	1904–1910	2.05	1.20	1.84	1.80	3.28	.97	.72	2.15	1.07	1.04	.50	1.32	17.97
Blanding	San Juan	6,000	1905–1918	2.03	1.55	1.42	1.06	.67	.41	1.43	1.47	1.19	1.81	1.53	2.18	16.70
Blue Creek	Boxelder	4,387	1878–1904	1.01	.77	.81	.83	.90	.48	.25	.36	.44	.87	.59	.87	8.19
Bluff	San Juan	4,300	1911–1918	.72	.49	.60	.44	.50	.10	1.19	.63	.48	.46	.03	.73	6.31
Brigham City	Boxelder	4,305	1895–1918	2.13	1.64	2.11	1.49	2.20	1.08	.81	.40	1.14	1.64	1.47	1.19	17.34
Burrville	Sevier	6,800	1911–1918	1.18	.98	.70	1.16	.62	.83	1.45	.51	.87	.89	.74	.56	10.45
Calino	Juab	....	1902–1905	.51	.83	1.18	.14	1.66	1.52	.02	.27	.33	.47	.20	.13	7.24
Canaan	Washington	5,000	1912–1917	2.16	1.52	.56	1.74	.52	.38	2.43	1.17	1.35	1.42	.83	.63	14.71
Castle Dale	Emery	5,500	1899–1918	.97	.78	.55	.67	.42	.63	.88	1.11	.94	.87	.74	.72	9.28
Castlegate	Carbon	6,120	1893–1897	1.07	.78	1.63	.27	.34	.53	.73	.64	1.28	.29	.60	1.27	9.43
Castle Rock	Summit	6,240	1904–1918	1.82	1.80	1.76	1.28	1.72	1.24	1.09	1.15	1.39	1.46	.96	.96	16.63
Cedar City	Iron	5,750	1899–1918	.94	.94	1.18	1.20	.95	.37	1.50	1.21	1.20	1.29	1.00	.83	12.70
Center	Tooele	4,250	1911–1916	1.67	1.08	1.16	1.06	.52	1.02	1.05	.60	.62	1.28	.86	.52	11.44
Cisco	Grand	4,385	1892–1914	.67	.94	.48	.39	.64	.10	.28	.32	.90	.67	.37	.51	6.50
Clarkston	Cache	5,930	1911–1918	1.74	1.84	1.70	1.61	1.88	1.53	.97	.50	1.19	1.79	1.69	.92	17.36
Corinne	Boxelder	4,240	1870–1918	1.41	1.22	1.31	1.11	1.48	.67	.49	.54	.73	1.11	.99	1.40	12.46
Coyote	Garfield	....	1902–1908	.58	.30	.76	.84	.72	.42	.78	1.00	.88	.67	.83	.39	8.21
Deseret	Millard	4,541	1892–1918	.69	.85	.89	.95	1.03	.39	.42	.46	.82	.71	.57	.50	8.28
Duchesne	Duchesne	5,515	1906–1918	.76	.60	.63	.66	.64	.75	.99	.93	1.31	1.08	.58	.55	9.48
East Portal	Wasatch	7,606	1912–1918	3.05	2.10	2.30	1.22	1.32	1.07	1.87	.90	1.80	2.43	1.48	1.52	21.06
Elberta	Utah	4,650	1902–1918	1.09	1.21	1.30	.92	1.19	.50	.63	.57	.96	1.01	.70	.72	10.80
Elkhorn	Uinta	6,657	1910–1918	.77	.56	.84	.53	.79	.78	1.27	.84	1.58	1.12	.30	.51	9.89
Emery	Emery	6,260	1901–1918	.56	.65	.46	.46	.52	.44	.80	1.21	1.14	.75	.36	.49	7.93
Enterprise	Washington	4,270	1905–1918	2.88	1.85	2.05	1.18	.83	.44	1.31	1.39	1.30	1.10	.97	.94	16.24
Erekson	Tooele	4,850	1911–1918	1.56	1.61	1.44	1.41	1.32	.97	1.11	.34	.89	1.09	1.06	.82	13.62
Escalante	Garfield	5,700	1901–1918	1.34	1.01	1.14	.50	.45	.50	1.66	1.71	1.07	1.12	.47	.72	11.69

Average monthly and annual precipitation (in inches) at Weather Bureau stations in Utah—Continued.

Station.	County.	Elevation (feet).	Years.	January.	February.	March	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
Farmington	Davis	4,267	1889-1918	2.29	2.23	2.63	2.07	2.39	0.98	0.65	0.73	1.19	1.74	1.47	2.04	20.41
Fillmore	Millard	5,100	1889-1918	1.16	1.45	1.86	1.63	1.55	.54	.84	.80	1.20	1.22	1.06	1.05	14.36
Fort Duchesne	Uinta	4,941	1888-1918	.54	.42	.64	.58	.71	.35	.55	.64	1.12	.64	.37	.50	7.06
Frisco	Beaver	7,318	1897-1912	.48	.76	.84	.61	.78	.34	.86	1.14	.81	.72	.47	.46	8.27
Fruitland	Duchesne	6,725	1910-1918	1.71	.94	.80	.65	.73	1.07	1.32	.74	1.59	1.73	.65	.76	12.69
Garland	Boxelder	4,248	1909-1918	1.63	1.61	1.34	1.31	1.89	1.12	1.16	.39	1.79	1.10	1.06	1.17	14.97
Garrison	Millard	4,850	1909-1917	.76	.54	.71	.54	.62	.20	.69	.55	.70	.74	.60	.20	6.95
Giles	Wayne	4,000	1895-1906	.38	.32	.38	.55	.50	.25	.51	.70	.72	.54	.55	.16	5.56
Government Creek	Tooele	5,277	1901-1918	1.20	1.29	1.95	1.39	1.64	.72	.71	.95	.92	.89	1.68	.86	13.60
Granger	Salt Lake	4,558	1912-1918	1.12	1.81	2.91	1.96	1.66	.95	1.23	.77	1.06	1.90	1.18	.75	17.30
Grantsville	Tooele	4,328	1906-1918	1.06	.91	1.21	1.14	1.34	.88	.79	.81	1.02	.99	.86	.56	11.57
Green River	Emery	4,080	1893-1918	.44	.40	.38	.30	.49	.38	.41	.55	.80	.62	.41	.34	5.62
Grouse Creek	Boxelder	5,300	1893-1918	1.39	.96	.71	1.14	.96	1.45	.67	.50	.66	.79	.56	1.00	10.79
Hanksville	Wayne	4,200	1910-1918	.59	.34	.49	.33	.26	.56	.80	.60	.77	.95	.33	.49	6.51
Heber	Wasatch	5,593	1893-1918	2.49	2.04	2.15	1.28	1.47	.66	.80	.91	1.18	1.35	1.26	1.61	17.20
Henefer	Summit	5,301	1900-1918	2.45	2.19	2.33	1.64	1.60	1.01	.80	.95	1.38	1.31	1.61	1.59	19.04
Hite	Garfield	3,000	1902-1914	.66	.68	.70	.36	.50	.31	.49	.63	.73	.75	.78	.69	7.28
Huntsville	Weber	5,100	1895-1918	2.98	2.53	2.65	1.55	2.07	.77	.67	.87	.99	1.59	2.05	1.86	20.58
Hurricane	Washington	3,800	1912-1918	1.53	1.34	1.27	1.47	.88	.32	1.56	.95	.96	1.49	.70	.56	13.12
Ibapah	Tooele	7,500	1903-1918	1.04	1.33	1.31	.89	1.98	.97	.91	.86	.69	.96	.67	.66	12.27
International	....do	5,370	1910-1911	.90	1.43	2.49	1.13	.86	.58	.72	.35	.83	1.72	1.20	.64	12.85
Iosepa	....do	4,356	1911-1917	1.39	1.10	1.42	1.32	.84	.78	.56	.19	.61	1.40	.76	.93	11.30
Kanab	Kane	4,925	1903-1917	1.82	1.30	1.72	1.19	.66	.26	1.30	.77	.79	.87	1.28	.78	12.83
Kanosh	Millard	5,250	1907-1918	1.37	1.53	1.36	1.53	1.57	.64	1.18	1.08	1.13	1.39	1.18	1.22	15.19
Kelton	Boxelder	4,230	1878-1918	.73	.65	.50	.61	.78	.48	.44	.22	.47	.53	.42	.70	6.53
Laketown	Rich	6,200	1900-1918	1.95	1.69	1.56	1.56	1.61	.95	.69	.75	1.27	1.27	1.07	.82	15.19
La Sal	San Juan	7,000	1901-1918	1.02	.97	.80	.77	.75	.63	1.27	1.14	1.19	.96	.78	.78	11.07
Leeds (near)	Washington	3,400	1913-1918	2.95	2.16	1.51	1.71	.93	.25	1.19	.78	.60	1.37	1.01	.90	15.04
Lehi	Utah	4,550	1904-1918	1.86	1.47	1.53	1.41	1.60	.67	1.03	1.02	1.31	1.39	1.01	1.30	15.68
Lemay	Boxelder	4,221	1911-1918	.50	.52	.47	.33	.49	.78	.22	.28	.31	.40	.21	.27	4.78
Levan	Juab	5,010	1889-1918	1.63	1.54	2.00	1.67	1.79	.55	.67	.85	1.22	1.24	1.01	1.54	13.71
Loa	Wayne	7,000	1892-1909	.48	.58	.62	.57	.34	.17	.88	1.25	.64	.40	.39	.49	6.80
Logan	Cache	4,507	1891-1918	1.80	1.57	1.97	1.67	2.28	.90	.63	.63	1.21	1.46	1.23	1.03	16.40
Low	Tooele	4,602	1911-1918	.50	.50	.64	.92	.55	.88	.16	.12	.56	.48	.21	.31	6.13
Lower American Fork	Utah	5,063	1914-1918	3.10	1.62	1.60	1.64	1.90	.81	1.17	.59	1.42	1.61	.89	1.42	17.77
Lower Mill Creek	Salt Lake	4,950	1914-1918	3.11	1.99	2.40	1.97	2.80	1.48	1.18	.35	1.65	1.80	1.55	1.45	21.85
Lucin	Boxelder	4,504	1905-1918	.68	.62	.25	.33	.73	.71	.48	.20	.43	.38	.28	.32	5.41
Lund	Iron	5,092	1903-1912	.18	.91	.87	.29	.63	.19	1.01	1.05	1.22	1.60	0	.02	7.97
Manila	Uinta	6,225	1910-1918	.41	.59	.50	1.74	1.29	.82	1.14	.54	1.11	1.39	.44	.40	10.37
Manti	Sanpete	5,575	1894-1918	1.28	1.21	1.52	1.19	1.18	.50	.83	.68	1.22	1.12	.97	.74	12.44
Marion	Summit	6,750	1905-1913	2.28	1.81	2.66	1.72	2.21	1.06	.74	1.63	1.54	1.28	1.61	1.75	20.27
Marysvale	Piute	5,830	1899-1918	.82	.83	1.08	.79	.93	.60	.95	1.42	1.25	1.00	.78	.76	11.21
Midlake	Boxelder	4,235	1911-1918	.69	.70	.86	.48	.42	.62	.36	.09	.30	.71	.16	.49	5.88
Midvale	Salt Lake	4,365	1912-1918	1.59	1.51	1.92	1.77	1.54	1.05	.07	.40	1.03	1.48	1.06	1.05	15.37
Milford	Beaver	4,962	1908-1918	.81	1.07	.84	.77	.32	.23	1.18	.48	.58	.87	.62	.90	8.67
Mills	Juab	4,911	1912-1918	1.95	.60	.49	1.20	.87	.58	1.14	.61	.84	1.02	.78	.45	9.63
Millville	Cache	4,848	1895-1918	1.80	1.53	2.10	1.70	2.20	.95	.54	.73	1.24	1.59	1.60	1.16	17.23
Minersville	Beaver	5,070	1897-1918	.92	.89	1.44	.90	1.05	.40	.95	.95	.89	.89	.81	.85	10.94
Moab	Grand	4,000	1890-1918	.92	.66	.93	.64	.78	.34	.86	.66	1.04	.90	.64	.96	9.33
Modena	Iron	5,479	1901-1918	.97	2.12	1.16	.88	.83	.30	1.43	1.45	1.03	.87	.52	.61	11.17
Monticello	San Juan	7,050	1902-1918	1.46	1.76	2.29	1.23	.81	.68	1.97	1.61	1.48	2.25	1.14	1.46	18.17
Morgan	Morgan	5,080	1903-1918	3.00	2.11	2.21	1.27	2.16	.98	.88	1.37	1.09	1.80	1.62	1.73	20.22
Moroni	Sanpete	6,000	1906-1918	2.30	1.33	1.36	1.52	1.01	.82	1.27	1.07	1.50	1.61	1.22	1.13	16.14
Mosida	Utah	4,510	1912-1918	1.10	1.34	.89	1.12	1.40	.55	.90	.32	.59	1.36	.55	.77	10.89
Mount Pleasant	Sanpete	5,859	1889-1910	1.18	1.76	1.69	.99	1.25	.43	.84	.72	1.02	.81	.70	1.26	12.65
Mountain Home	Duchesne	6,000	1913-1918	2.23	.75	.65	.98	.85	1.00	1.56	.91	1.43	1.35	.45	.53	12.69
Nada	Beaver	5,060	1914-1918	1.95	1.36	1.44	.95	1.15	.35	1.81	.99	.61	.97	.48	.75	12.81
Nephi (near)	Juab	5,119	1904-1918	1.38	1.14	1.43	1.31	1.56	.70	.78	1.01	1.06	1.09	.92	1.06	13.42
New Castle	Iron	5,150	1911-1916	1.35	.86	.71	1.08	.97	.60	1.32	1.51	1.18	1.53	.70	.59	12.43
New Harmony	Washington	5,300	1911-1918	2.97	2.73	3.42	1.77	.85	.67	2.41	1.20	1.74	2.08	.74	1.43	22.14
Oak City	Millard	4,900	1905-1918	1.22	1.44	1.74	1.65	1.66	.60	.72	.72	1.43	1.27	1.25	1.10	14.80
Ogden No. 1	Weber	4,310	1902-1912	2.32	2.26	2.49	1.74	2.38	1.09	.34	.83	1.05	1.34	1.19	1.89	18.92
Ogden No. 2	....do	4,310	1870-1918	1.70	1.61	1.82	1.45	1.74	.74	.37	.61	.88	1.36	1.08	1.58	15.02
Orderville	Kane	6,660	1910-1918	2.78	1.58	1.96	1.32	.68	.49	2.24	1.15	1.84	1.28	.90	.83	16.98
Pahreah	....do	4,000	1895-1900	1.10	.68	.30	.88	.62	.74	.73	1.22	.72	.88	.39	.19	8.45
Panguitch	Garfield	6,560	1904-1918	1.07	.70	1.14	.91	.60	.30	1.78	1.48	.94	.94	.73	.46	11.05
Park City	Summit	7,000	1893-1918	3.09	2.84	3.04	1.42	1.22	.68	1.20	1.14	1.11	1.20	1.28	2.02	20.24
Park Valley	Boxelder	5,200	1911-1918	.84	.88	.69	.79	.92	1.54	.99	.68	.75	1.08	.40	.65	10.19
Parowan	Iron	5,970	1891-1918	1.10	1.29	1.00	1.00	1.08	.36	1.36	1.41	1.09	.94	.74	.92	12.80
Payson	Utah	4,637	1904-1918	2.11	1.80	2.33	1.92	2.20	.93	.87	.68	1.23	1.66	1.46	1.43	18.62
Pine Valley	Washington	6,000	1911-1917	.72	2.37	1.82	2.41	.85	.82	2.51	2.89	.89	3.48	1.14	.76	20.66
Pine View	Summit	6,335	1911-1918	2.43	1.07	1.06	1.11	.90	1.55	.89	.74	2.16	1.66	1.04	.89	15.50
Pinto	Washington	5,907	1897-1918	1.47	1.39	1.94	.99	1.07	.33	1.43	1.80	1.32	1.38	1.05	.79	14.96
Plateau	Sevier	7,000	1902-1907	1.19	1.35	2.01	1.37	2.09	.60	1.04	1.05	1.36	.69	1.22	1.22	15.19
Plateau (near)	....do	7,000	1905-1910	1.39	1.07	1.26	1.07	1.59	.29	1.09	2.44	1.60	.90	.82	.99	14.51
Price	Carbon	5,566	1911-1918	1.07	.58	.83	.98	.39	.78	1.07	.50	1.47	.55	.63	.82	9.82
Provo	Utah	4,532	1891-1918	1.72	1.64	1.68	1.36	1.60	.78	.57	.65	1.02	1.31	1.11	1.43	14.87
Randolph	Rich	6,442	1893-1918	.90	.74	.88	.96	1.11	1.00	1.05	.91	1.19	.79	.47	.54	10.54
Reed	Beaver	4,900	1913-1915	.12	.44	.12	.85	.42	.06	2.08	.13	.85	.40	.45	.37	7.49
Revere	Salt Lake	5,066	1911-1915	1.58	1.13	1.54	1.57	1.03	1.11	.87	.70	1.11	1.34	.74	1.11	13.83
Richfield	Sevier	5,350	1890-1918	.70	.84	.90	.83	.31	.38	.66	.67	.76	.83	.52	.65	8.25
Richmond	Cache	4,529	1912-1918	2.56	2.33	2.56	2.10	2.45	1.67	1.03	.68	1.59	2.13	1.62	1.30	22.02
Riverdale	Weber	4,310	1914-1918	1.95	1.64	1.02	1.53	1.22	.98	.78	.17	1.36	1.60	.99	.69	13.94
St. George	Washington	2,880	1890-1918	1.05	1.04	.89	.50	.39	.11	1.34	.90	.75	.63	.49	.64	8.73
Saltair	Salt Lake	4,220	1904-1918	1.41	1.26	1.89	1.49	1.34	1.21	.63	.74	1.08	1.33	1.21	.86	14.65
Salt Lake City	....do	4,408	1874-1918	3.89	1.41	1.81	.59	1.32	.20	.76	.61	2.10	1.13	1.77	.52	16.11
Santaquin	Utah	5,250	1914-1918	2.99	1.78	1.76	2.08	2.12	1.42	.72	.16	.70	1.60	1.11	1.29	17.73
Scipio	Millard	5,280	1895-1918	1.66	1.82	1.97	1.43	1.36	.46	.43	.95	1.17	1.30	1.14	1.13	14.82
Scofield	Carbon	7,625	1893-1918	3.50	1.64	1.33	1.88	1.44	1.48	2.06	2.08	1.62	1.57	1.40	1.41	21.39
Silver City	Juab	6,127	1910-1917	1.87	1.27	1.15	.85	1.24	.07	.93	.38	.87	1.90	.70	1.14	13.63
Soldier Summit	Utah	7,454	1892-1913	1.36	1.69	1.68	.64	.85	.28	.58	.76	.93	.61	1.17	1.48	12.04
Snake Creek	Wasatch	5,950	1914-1918	4.26	3.45	2.25	1.84	1.38	.81	1.25	.85	2.10	1.90	1.40	2.60	24.09
Snowville	Boxelder	4,550	1890-1918	1.31	1.02	1.48	1.11	1.60	.74	.58	.40	.60	1.13	.82	1.03	11.82
Spanish Fork	Utah	4,585	1910-1918	2.26	1.47	1.80	1.75	1.77	.94	.78	.31	1.18	1.90	1.47	1.57	17.40
Springdale	Washington	3,500	1904-1918	1.92	1.68	2.02	1.32	.74	.14	1.25	1.57	1.50	1.21	1.07	1.18	15.60
Standrod	Boxelder	6,000	1905-1918	1.30	.94	1.23	1.22	1.97	1.76	1.31	1.01	1.15	1.43	1.16	.70	15.18

Average monthly and annual precipitation (in inches) at Weather Bureau stations in Utah—Continued.

Station.	County.	Elevation (feet).	Years.	January.	February.	March	April.	May.	June.	July.	August.	September.	October.	November.	December.	Annual.
Sunnyside	Carbon	5,280	1905-1918	1.42	1.13	1.35	1.12	1.13	0.78	1.46	1.36	1.88	1.05	0.99	0.81	14.64
Teasdale	Wayne	7,000	1893-1918	.60	.71	.66	.65	.47	.48	1.36	1.36	.90	.67	.47	.51	8.84
Terrace	Boxelder	4,550	1872-1904	.63	.40	.47	.40	.71	.26	.11	.15	.27	.23	.38	.63	4.61
Thistle	Utah	5,033	1892-1918	2.19	1.75	1.85	1.32	1.22	.70	.83	.81	1.08	.95	1.19	1.68	15.57
Thompsons	Grand	5,150	1911-1916	.22	.32	1.12	.34	.27	.50	.92	.17	1.03	1.04	.83	.59	7.55
Tooele	Tooele	4,900	1896-1918	1.53	1.45	2.09	1.83	2.23	.88	.74	.83	1.04	1.84	1.46	1.02	16.52
Tremonton	Boxelder	4,250	1914-1918	1.47	2.46	1.16	1.03	1.95	.99	.98	.15	1.27	1.18	.71	.72	14.07
Tropic	Garfield	7,000	1897-1918	1.17	1.05	.90	.71	.63	.37	1.47	1.51	1.20	.78	.79	1.00	11.38
Trout Creek ranger station.	Juab	4,850	1905-1907	.68	.95	.97	.48	1.10	.79	.09	1.10	1.09	.57	1.15	.44	9.41
Vernal	Uinta	5,266	1895-1918	.77	.62	.80	.67	.85	.32	.70	.58	1.25	.91	.60	.52	8.59
Victor	Emery	5,250	1913-1918	.71	.37	.27	.45	.37	.55	1.15	.32	1.02	.72	.41	.43	6.07
Watson (near)	Uinta	6,210	1911-1918	.97	.73	.88	.83	.89	.92	1.39	.87	1.05	1.21	.72	.70	11.16
Wellington	Carbon	5,540	1900-1909	.53	.59	.47	.53	.32	.19	.27	.91	.90	.35	.55	.58	6.39
Wendover	Tooele	4,237	1911-1918	.33	.41	.24	.38	.60	.56	.37	.12	.42	.38	.18	.23	4.22
Whiskey Creek	Millard	4,850	1911-1918	1.32	1.61	1.29	1.38	1.02	.45	.45	.12	.86	1.00	.90	.93	11.33
Woodruff	Rich	6,500	1897-1918	.85	1.00	1.05	.81	1.07	.96	.77	.70	.63	.99	.42	.65	9.90
Woodside	Emery	4,645	1911-1916	1.05	.55	.62	.20	.31	.49	.57	.32	1.14	.66	.48	.53	6.92

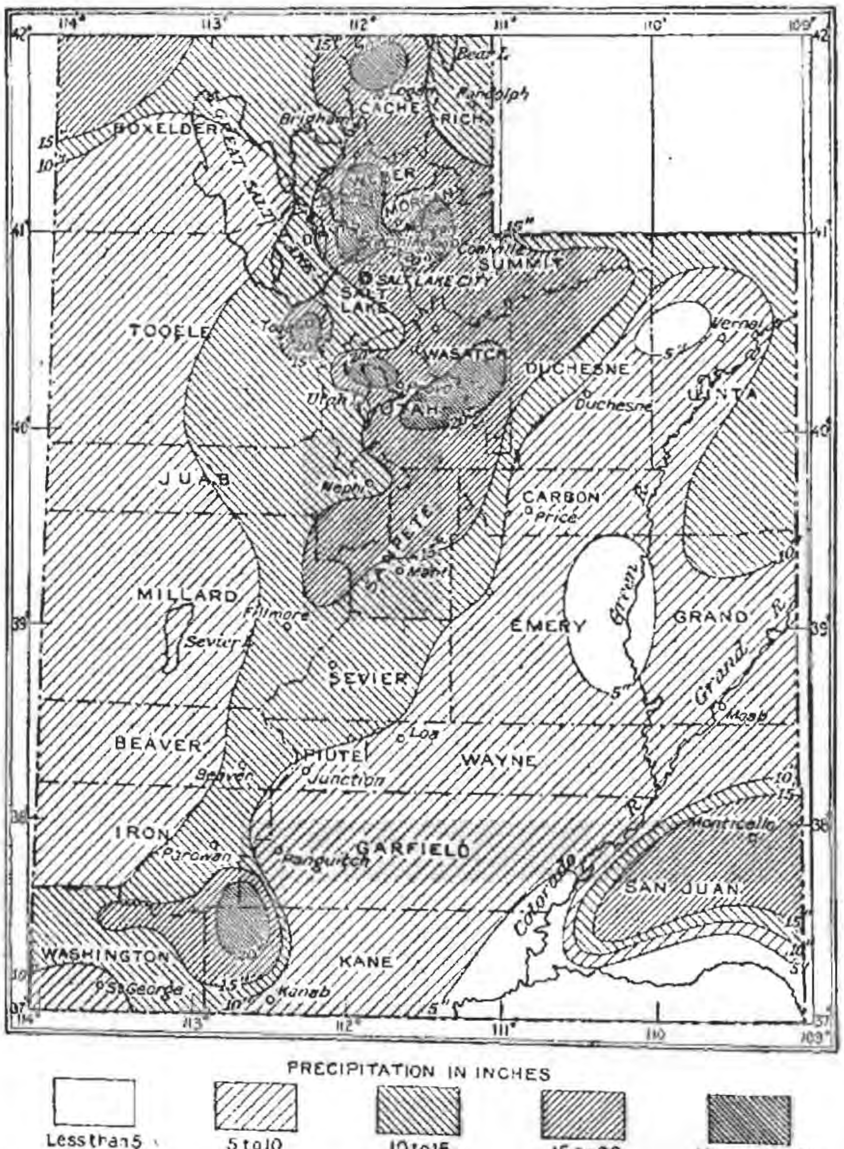


FIGURE 1.—Map showing rainfall in different sections of Utah. From United States Weather Bureau Reports.

VEGETATION.

Except in some alkali areas the soil of Utah is generally fertile, and the native vegetation is largely dependent on the temperature and the precipitation. In the higher areas, notably the Uinta Mountains, the Wasatch Range, and the High Plateau, timber is abundant. At lower levels this gives place to scrub pine, juniper (cedar), and oak, and these in turn to sagebrush and other desert plants. In the lowest and driest areas the vegetation is scanty and confined to desert plants that require little moisture. Bunch and other grass grows rather plentifully over most of the State but has been greatly reduced over large areas by overgrazing.

AGRICULTURE.

Until recent years agriculture has been confined to the areas where irrigation was possible, and the more important agricultural interests have grown up around the points where the streams emerged from the mountains onto the flat area, notably along the west front of the Wasatch Range and its southern extension. Farther west in the Great Basin cultivated lands are limited to a few ranches irrigated from small streams coming from the higher ranges and from a few wells.

Some of the flat-bottomed valleys east of the Wasatch Range have proved exceedingly fertile, especially the Sevier and Sanpete valleys. South of the Uinta Mountains is an area containing large tracts that can be irrigated and that has in some degree been brought under cultivation. In southern and southeastern Utah only small areas are cultivated, and though these can be considerably enlarged most of the land never can be irrigated.

In recent years cultivation without irrigation has been attempted in several sections of the State and in the higher areas, where there is considerable precipitation, has been successful. Large tracts of this character have not yet been brought under cultivation, many of them because of lack of transportation or of water suitable for domestic use and for stock. Probably a large acreage of this type of land will eventually be utilized.

Since the earliest settlement of the State stock raising has been an important industry. Cattle, sheep, and horses range over practically all of the State that has not been given over to more intensive agriculture. In many sections the range has been overstocked and seriously damaged, but in recent years the regulation governing the forest reserves has brought about great improvement and will doubtless eventually lead to the regulation of the range in general.

Practically all the important mining districts are within easy reach of farming sections, where all the essential agricultural products may be had at reasonable prices.

TRANSPORTATION.

In the Great Basin region railroads can be constructed along the flat valleys between the ranges at moderate cost, and such extensions have been made wherever traffic has seemed to warrant. The principal mining camps and larger agricultural communities are now provided with railroad transportation. Large areas, however, are without railroads and have consequently been greatly retarded in their development. The transcontinental lines have greatly benefited large areas that of themselves would not have attracted a railroad.

In eastern Utah the topography is usually not favorable to cheap railroad construction, and transportation facilities are meager. The Denver & Rio Grande Railroad traverses the central part and has branches to some of the more important coal deposits. The history of railroad development in the State is discussed on page 118.

In the thickly settled parts of Utah the highways are good, but in the large, sparsely settled parts they are generally poor, though a system of improved roads that will greatly aid development is being gradually extended over the State.

WATER POWER.

By Herman Stabler.

The streams of Utah warrant the development of about three-quarters of a million horsepower under conditions of low-water flow, and this amount may be nearly doubled by the use of storage reservoirs. About 40 per cent of the power possibilities of the State can be developed only in large units on Colorado River and its main tributaries, the Green, Grand, and San Juan. The remainder is distributed chiefly among the smaller mountain streams and can be developed in relatively small units in accord-

ance with local needs. Generally speaking, the mountain areas, particularly those included in forest reserves, abound in opportunities for the development of small power plants. Such small units are of importance to mines that are beyond the limits of transmission from existing power systems of public-utility corporations. That they have proved advantageous in the past is clearly indicated by the fact that of the 60 developed water-power plants in the State only 3 are of more than 10,000 horsepower capacity, whereas 20 are of 1,000 to 6,000 horsepower, 9 of 500 to 1,000, and 28 of less than 500.

The Utah Power & Light Co., a relatively recent combination of 20 to 30 plants, many of which were originally developed for local mining use, is by far the most important public-utility corporation that provides electric service in the State. Its chief source of water power is Bear River and its tributaries in Idaho and Utah, and Provo, Ogden, and Weber rivers in Utah, though several smaller streams are utilized. This company serves the eastern part of the drainage basin of Great Salt Lake from the Utah-Idaho line south to Silver City, and has recently constructed a line from Springville to Helper, Blackhawk, and Huntington, in the basin of Price River. An extension of this line along the general route of the Denver & Rio Grande Railroad into Colorado to connect with the system of its subsidiary, the Western Colorado Power Co., is contemplated. The two companies together operate hydroelectric plants with a generator capacity of over 130,000 kilowatts and have an annual output of electric energy in excess of 500,000,000 kilowatt-hours, over half of which is used by the mining industry. Among the large mining interests served are the Utah Copper Co. and the American Smelting & Refining Co.

The topographic map (Pl. I, in pocket) shows the location of the several water-power plants and transmission systems and of the principal undeveloped water-power possibilities; and the following table sets forth the principal facts with reference to the water-power plants whose electric output is available for use in the State. Plants numbered 1 to 45, inclusive, are operated as public-utility properties, and the remainder are operated solely for the municipalities or mining companies specified.

Water-power plants of power systems operating in Utah.

No.	Name of power system.	Name of plant and stream utilized.	Location of plant.			Horsepower of water wheels.
			T.	R.	Sec.	
			Idaho; Boise meridian.			
1	Utah Power & Light Co.	Georgetown, Georgetown Creek	11 S.	44 E.	4	300
2	do	High Creek, Cub Creek	15 S.	40 E.	34	1,000
3	do	Paris, Paris Creek	14 S.	43 E.	9	1,180
4	do	Grace, Bear River	10 S.	40 E.	21	50,000
5	do	Cove, Bear River	10 S.	40 E.	33	10,000
6	do	Oneida, Bear River	13 S.	40 E.	23	27,000
			Utah; Salt Lake meridian.			
7	do	Weber, Weber River	Weber Canyon			5,000
8	do	Pioneer, Ogden River	Ogden			10,600
9	do	Granite, Big Cottonwood Creek	2 S.	1 E.	25	2,400
10	do	Stairs, Big Cottonwood Creek	2 S.	2 E.	30	2,400
11	do	Alpine, Dry Creek	4 S.	2 E.	8	3,000
12	do	Lower American Fork, American Fork	4 S.	2 E.	32	1,274
13	do	Upper American Fork, American Fork	4 S.	2 E.	28	1,610
14	do	Battle Creek, Battle Creek	5 S.	2 E.	22	4,000
15	do	Wheelon, Bear River	13 N.	2 W.	23	12,300
16	do	Davis, Farmington Creek	3 N.	1 E.	17	537
17	do	Jordan Narrows, Jordan River	4 S.	1 W.	15	1,344
18	do	Logan, Logan River	12 N.	1 E.	36	3,000

Water-power plants of power systems operating in Utah—Continued.

No.	Name of power system.	Name of plant and stream utilized.	Location of plant.			Horse-power of water wheels.
			T.	R.	Sec.	
			Utah; Salt Lake meridian.			
19	Utah Power & Light Co.	Murdock, Provo River	2 S.	5 E.	32	3,300
20	....do	Upper Mill Creek, Mill Creek	1 S.	2 E.	27	650
21	....do	Lower Mill Creek, Mill Creek	1 S.	1 E.	36	2,600
22	....do	Olmstead, Provo River	6 S.	3 E.	7	10,800
23	....do	Park City, Ontario Tunnel	2 S.	4 E.	24	300
24	....do	Riverdale, Weber River	5 N.	1 W.	19	5,750
25	....do	Santaquin, Santaquin Creek	10 S.	1 E.	13	1,700
26	....do	Snake Creek, Snake Creek	3 S.	4 E.	21	2,000
27	....do	Hyrum, Blacksmith Fork	10 N.	1 E.	11	4,300
28	....do	Williard, Williard Creek	8 N.	2 W.	23	700
29	Beaver River Power Co.	Beaver River, Beaver River	29 S.	6 W.	24	2,500
30	Bennion, Hyrum & Sons Co.	Bennion's, Jordan River	Taylorville			100
31	Big Springs Electric Co.	Big Springs, Big Springs Creek	13 S.	2 E.	36	260
32	Clark Electric Power Co.	Tooele, Settlement Creek	3 S.	4 W.	33	250
33	Como Light & Power Co.	Morgan				500
34	Dixie Power Co.	Santa Clara Creek	43 S.	18 W.	11	1,100
35	Electric Power & Milling Co.	Orangeville				125
36	Nunn, L. L.	Gunnison, Sixmile Creek	19 S.	2 E.	3	550
37	Progress Co., The	Kunsden, Big Cottonwood Creek	2 S.	1 E.	23	200
38	....do	State Street, Big Cottonwood Creek	2 S.	1 E.	8	200
39	Spring City Light & Milling Co.	Spring City, Oak Creek	16 S.	4 E.	2	22
40	Swan Creek Electric Co.	Swan Creek, Swan Creek	14 N.	5 E.	6	125
41	U. S. Reclamation Service	Spanish Fork, Spanish Fork	8 S.	3 E.	35	1,200
42	Vernal Milling & Light Co.	Vernal, Ashley Creek	3 S.	21 E.	7	350
43	Wasatch Mines Co.	Alta, Little Cottonwood Creek	3 S.	2 E.	10	800
44	Municipal	Beaver, Beaver River	29 S.	7 W.	14	200
45	....do	Brigham, Box Elder Creek	9 N.	1 W.	20	1,200
46	....do	Ephraim, Cottonwood Creek	17 S.	3 E.	23	300
47	....do	Fairview, Cottonwood Creek	13 S.	5 E.	32	126
48	....do	Heber, Provo River	3 S.	5 E.	7	1,280
49	....do	Helper, Price River	12 S.	9 E.		250
50	....do	Hyrum, Blacksmith Fork	10 N.	1 E.	2	174
51	....do	Logan, Logan River	12 N.	2 E.	29	800
52	....do	Manti, Manti Creek	18 S.	2 E.	8	100
53	....do	Monroe, Monroe Creek	25 S.	3 W.	22	100
54	....do	Mount Pleasant, Pleasant Creek	15 S.	5 E.		275
55	....do	Murray, Little Cottonwood Creek				1,200
56	....do	Nephi, Salt Creek	13 S.	1 E.	2	250
57	....do	Parowan, Center Creek	34 S.	9 W.	24	86
58	....do	Springville, Hobble Creek	8 S.	4 E.	6	150
59	....do	St. George, Cottonwood Creek	41 S.	15 W.	30	60
60	....do	Utah State, Logan River	12 N.	1 E.	36	600
61	Michigan-Utah Mining Co.	Alta, Little Cottonwood Creek	3 S.	2 E.	11	50
62	Ophir Hill Consolidated Mining Co.	Ophir, Ophir Creek	5 S.	4 W.	28	220
63	....do	South Willow Creek, South Willow Creek	3 S.	6 W.	27	300
64	Sevier-Miller Coalition Mining Co.	Kimberly, Clear Creek	25 S.	4½ W.	34	300

PHYSIOGRAPHIC DEVELOPMENT.

GENERAL OUTLINE.

In Mesozoic time a large part of what is now the Basin province was probably above sea level and was being actively eroded, and a part at least of its waste was being deposited to the east, where it formed a great thickness of Triassic, Jurassic, and Cretaceous shales and sandstones. The boundary between the area of erosion and that of deposition is generally regarded as approximately the eastern limit of the Great Basin, though in the latitude of the Mineral and Star ranges Triassic sediments at least were deposited well within the Basin province.

At the end of the Mesozoic or early in the Cenozoic era there occurred a general uplift accompanied by folding, by overthrust and other faulting, by igneous intrusion, and by doming which was at least in part the result of intrusion. (See Pl. XI, p. 100.) Erosion of the

more greatly uplifted surfaces began at once, the resulting waste being laid down on lower ground near by or carried oceanward. The period of upheaval and intrusion was overlapped or followed by one of volcanism, during which immense quantities of lava and tuff were erupted, especially in southern Utah.

The transfer of this great volume of magma from the earth's interior to its surface was perhaps the cause of a widespread fracturing and differential settling of the crust which followed. The greatest relative subsidence took place in what is now the Great Basin, whose eastern margin was marked out by a persistent zone of normal faults on which the downthrow was to the west. The Basin Ranges were outlined by other great north-south faults; smaller faults and some persistent flexures affected the Plateau region; and the Wasatch Range was relatively upheaved and tilted eastward. The masses blocked out by these movements have since been continuously modified by erosion and deposition. Erosion has been most active in the elevated eastern area, and its products have largely been deposited in the Great Basin or carried oceanward, the main theaters of erosion and of deposition having exchanged places since Mesozoic time.

WASATCH MOUNTAINS.

The Wasatch Mountains were the scene of vigorous action in both periods of deformation. The range is characterized as a whole by strong folding and thrust faulting and in part by other faults and by intrusion. The structure indicates that in the period during which these movements occurred the range was upheaved as a whole with reference to the tract on the east, though it may not have been raised higher than the region to the west was at that period. After being greatly reduced by erosion it was again relatively upheaved by faulting. The thesis that its western face is a fault scarp of westward dip was first advanced by Emmons [1] and was confirmed by some of the latest field work of G. K. Gilbert.[2]

It is possible, though less certain, that the east side of the range, where it is sharply defined, is also determined by faults with downthrow to the east. At any rate, the decline in the height of the summits from west to east indicates that the fault block was tilted eastward. The range is allied by its physiographic history, as well as by its drainage, to the Basin Ranges, though it is part of an upland whose topography, as shown on pages 57 and 58, stands in strong contrast to that of the Great Basin.

The range has been thoroughly dissected, though the westward-flowing streams, being of steeper grade in their lower than in their upper courses, show incomplete adjustment to the upheaval by faulting. The higher parts of the range have been strongly glaciated. Some moraines extend to the western base; these have been broken by recent faulting along the old scarp.

UINTA MOUNTAINS.

The Uinta Mountains were formed primarily as the result of an arching up along an east-west axis, which took place later than most of the early deformation of the Wasatch belt. (See p. 252.) The present form of the Uinta, however, has been determined by many other factors than this primary uplift. Early in the Tertiary the crest of the arch became maturely dissected by stream erosion. Certain of the more powerful streams cut headward nearly or quite through the range, as they are now cutting in some of the Basin Ranges, notably at Squaw Springs Pass, in the San Francisco Range, and in Sevier Canyon, in the Canyon Mountains. Much of the material eroded from the arch was laid down on the adjacent parts of the Wyoming Basin at the north and of the Plateau region at the south. The original surface of these deposits is thought to be approximately represented by the flat summits of Diamond Mountain, Split Mountain, and Yampa Plateau on the south side of the range, and similar headlike remnants on the north side of the range have been described by Rich.[3]

The remarkable course of Green River athwart the axis of the range is thought to have been established at the time when the range was thus worn down and flanked by gravel plains which probably coalesced in some of the lower passes. This explanation of Green River as superimposed is regarded as more probable than the once popular view that the stream maintained upon the slowly

[1] U. S. Geol. Expl. 40th Par., vol. 2, p. 345, 1877.
[2] Gilbert, G. K., unpublished manuscript.
[3] Rich, J. L., The physiography of the Bishop conglomerate, southern Wyoming: Jour. Geology, vol. 18, p. 601, 1910.

RELIEF MAP SHOWING PARTS OF ROCKY MOUNTAIN, COLORADO PLATEAU, AND GREAT BASIN AREAS.

From map prepared by J. H. Renshawe.

A. ROCKY RANGE; PHYSIOGRAPHICALLY OLD MOUNTAINS.

B. BEAVER LAKE MOUNTAINS; PHYSIOGRAPHICALLY OLD MOUNTAINS DEEPLY BURIED IN DÉBRIS.

C. FRONT OF WASATCH RANGE, NEAR LITTLE COTTONWOOD CANYON; PHYSIOGRAPHICALLY YOUNG MOUNTAIN RANGE.

arching strata a course determined while these strata still lay flat.[1]

Intermittent uplift of the range as a whole is indicated, however, by the terracing of the stream valleys in the gravel deposits. The terraces presumably were formed in periods of relative quiescence during which the streams widened their valleys in the softer flanking formations but were able only to deepen their canyons in the hard rocks that form the core of the range; in periods of uplift the channels were deepened in the soft formations also.

The large canyons of the range have been strongly glaciated, and heavy moraines extend beyond the mouths of many of these canyons. The glacial features have been described by Atwood.[2]

PLATEAU PROVINCE.

TOPOGRAPHIC FEATURES.

The rocks exposed in the Plateau regions of Utah are chiefly sedimentary strata that range in age from pre-Cambrian to Tertiary. These rocks are capped on the High Plateau by a thick layer of volcanic rocks and are locally injected with intrusive rocks, the more important bodies of which are laccolithic. The strata lie for the most part nearly flat, but they have been deformed by some faults and flexures and domed up by the laccoliths. The general horizontality of the bedding and the rather simple dislocations by which it is affected determine the topographic character of the region.

The usual horizontal stratification is expressed by the prevalence of terraces of differential erosion. The rise from Colorado River in the region of the Grand Canyon to the High Plateau is a series of steps, the abrupt rises being separated by broad, nearly flat benches surfaced with relatively hard and resistant rock and underlain by softer material. In northern Arizona and southern Utah this bench topography is developed on a magnificent scale; farther north it is less marked, and along Green River, south of the Uinta Mountains, where the valley is in Tertiary rocks, it is on a greatly reduced scale, though still conspicuous.

The rather sharp, generally north-south monoclinal folds that traverse the region have been carved by erosion into strong topographic features. Massive formations, as the White Cliff sandstone, form prominent ridges or hogbacks well above the level of the area, on the downwarp side of the folds. Such ridges, seen in Comb Wash, the Water Pocket flexure, the east border of the San Rafael Swell, the Paria flexure, and others (see Pl. II), are very striking though minor features of the Plateau region.

Where the rocks have been elevated and domed by intrusive masses, as in the Henry, Abajo, and La Sal mountains, the soft strata have been etched out by erosion, leaving the harder formations as encircling ridges through which the main streams have cut passes.

Long lines of north-south cliffs that follow lines of faulting may be due either to the actual raising or lowering of the surface on one side of the fault line relative to that on the other side, or perhaps more commonly to bringing a soft formation against a hard resistant one, the subsequent denudation quickly lowering the soft rock and leaving the hard rock standing as a cliff.

DEVELOPMENT.

At the close of Mesozoic or early in Cenozoic time the Plateau region was elevated, somewhat folded, and probably broadly domed and faulted. Erosion of its higher areas began forthwith, and the sediment derived from them was deposited in the lower areas.

Gradually a general northwest-southeast drainage system, corresponding in general to that of the present Colorado River, was developed across it. Erosion was naturally at first most rapid in the lower portion of this drainage system, and doubtless deep main valleys and a well-developed system of tributaries drained the area to the south, while sedimentation, at least in local areas, was still progressing to the north. The drainage system, however, gradually extended its headwaters into areas of previous deposition and began the removal of the sediments.

Since the beginning of Tertiary time there have been several periods of uplift, followed by periods of relative stability or possibly of partial subsidence. Following a period of uplift the streams cut narrow, steep-walled canyons. During a long period of stability these canyons are gradually broadened into flat, gravel-floored valleys, in which, on the renewal of uplift, narrow canyons are cut.

Most of the valleys of the Plateau province can be attributed with much certainty to weathering and to stream erosion. Some of

[1] This problem is fully discussed by E. T. Hancock, The history of a portion of Yampa River, Colo., and its possible bearing on that of Green River: U. S. Geol. Survey Prof. Paper 90, pp. 183-189, 1915.

[2] Atwood, W. W., Glaciation of the Uinta and Wasatch mountains: U. S. Geol. Survey Prof. Paper 61, 1909.

those in the transition zone between the Plateau and Basin provinces have, however, been generally regarded as due primarily to structural rather than erosional causes. Such, for example, is the Sevier Valley, which in its middle course at least, has been considered as resulting from the settling of a block between two great faults, forming a fault valley or "graben."

CORRELATION WITH UINTA RANGE.

Systematic correlation of the physiographic forms in the Uinta and Plateau regions has never been undertaken but presents a problem of great interest. It can best be accomplished by carefully following the typical forms from one region to the other. As has already been noted, there are gravel-covered benches at different elevations in the Uinta Range, and these seem to find their counterparts in similar benches around the higher mountain groups of the Plateau province, notably in the La Sal and Abajo and less prominently in the Henry mountains. These benches, which evenly truncate upturned strata of different powers of resistance, were undoubtedly formed during a period of stability, and are doubtless to be correlated with certain benches that have been developed in areas of essentially horizontal rocks. In the areas of horizontal rocks, however, it is frequently difficult to determine whether a given bench represents a definite stage of degradation, whether it has resulted from the differential erosion of hard and soft strata, or whether it is due to both causes. Correlation of the forms developed at different localities, unless actually traced one into the other, is therefore open to doubt.

CORRELATION WITH WYOMING AND COLORADO.

Westgate and Branson,[1] Blackwelder, and others have worked out in considerable detail the physiographic history of areas in Wyoming that probably find corresponding features in the Uinta and the Plateau regions. Blackwelder [2] summarizes the physiographic history of central western Wyoming as follows:

Divested of details and qualifications, the history of the district may now be reviewed in general terms. About the close of the Cretaceous period, the entire region was probably a monotonous plain underlain by unconsolidated sediments. Soon thereafter tangential forces within the earth's crust produced a series of moderate folds, trending northwest and southeast. The process of folding tended to produce a series of mountain ranges and basins corresponding to the anticlines and synclines; but the uplifts were certainly being eroded even while they were growing, and after the disturbance ceased they continued to be worn down until the surface became a well-dissected mountainous or hilly region interspersed with wide, relatively flat basins.

In the Wasatch or Lower Eocene epoch, terrestrial sediments began to accumulate in the lowlands, probably in response to mild warping movements and perhaps climatic changes, which disturbed the activities of the previously graded streams. * * * Somewhat later, probably near the middle of the Miocene epoch, the district was notably warped and locally faulted in part along the structural lines established at the close of the Cretaceous, but in part at variance with them. It is probable that this mid-Tertiary disturbance involved also a general elevation which left the region above base-level, and therefore subject chiefly to erosion rather than to sedimentation.

From the mid-Tertiary revolution down to the present time the history of western Wyoming is a chronicle of denudation. * * * The progress of general stream erosion was evidently not steady but was interrupted by successive elevatory movements or other changes which compelled the readjustment of stream activities.

Atwood [3] has summarized the post-Mesozoic history of the San Juan Mountain region, Colo., whose movements are doubtless to be correlated with those of eastern Utah, as follows:

At the close of the Mesozoic era and the opening of the Cenozoic era there were mountain-making movements which affected the entire Rocky Mountain province of North America, and the great dome which was then formed in the San Juan area was at once subjected to vigorous erosion.

* * * The western portion of the San Juan Mountain area was reduced to a surface of slight relief which may be thought of as a peneplain.[4] This peneplain bordered on the west a higher area of mountainous character, which supplied the material for the Telluride conglomerate. The deposition of gravels upon this peneplain surface was probably due to some uplift and rejuvenation of the streams in the eastern portion of the range. After the deposition of the Telluride conglomerate there was further erosion in the range, and then came the three great epochs of volcanism, the San Juan, the Silverton, and the Potosi. During these epochs of volcanism a great volcanic plateau was developed. By this time the Miocene epoch had been reached and possibly passed, and with the quieting down of volcanic activity began the erosion and dissection of the volcanic plateau. During this period of dissection an-

[1] Westgate, L. G., and Branson, E. B., The Cenozoic history of the Wind River Mountains, Wyo.: Geol. Soc. America Bull., vol. 23, p. 739, 1912.

[2] Blackwelder, Eliot, Post-Cretaceous history of the mountains of central western Wyoming: Jour. Geology, vol. 23, No. 4, pp. 330–340, 1915.

[3] Atwood, W. W., Eocene glacial deposits in southern Colorado: U. S. Geol. Survey Prof. Paper 95, pp. 22–24, 1915.

[4] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Silverton folio (No. 120), 1905.

other generation of San Juan Mountains were carved, this time out of volcanic débris and great lava flows.

With the redoming of the area, which involved the warping or doming of the summit peneplain, another cycle of erosion was begun.

BASIN PROVINCE.

CHARACTER.

The Basin province, as already indicated, is characterized by a series of nearly north-south ranges rising above a plateau of broad, flat desert valleys 4,000 to 5,000 feet above sea level.

The ranges show great diversity in composition and structure. Many are complexes of sedimentary, intrusive, and extrusive rocks, the complexity being especially prominent in the Tushar-San Francisco intrusive zone. Some of them exhibit little folding, while in others, as the Tintic and Oquirrh, folding is an important structural feature.

A characteristic of the ranges that has been recorded by several observers is that their fronts, which truncate rocks of very different degrees of resistance to denudation, form essentially straight lines, though the variation in the amount of erosion that has taken place in the different rocks within the range may be pronounced. The trend of the ranges bears no close relation to the internal structure. Where folding is important, as in the Oquirrh Range, the general trend of the range is at an angle to the trend of the folds, so that along the margins of the ranges the folds are truncated. This is true also of the Wasatch Range.

In several ranges, especially the southern ones, the sedimentary rocks dip in one general direction throughout. In some of these the uppermost formation consists of flows of lava having the same attitude as the underlying sedimentary rocks. (See fig. 2.)

Extending outward from the principal valleys in the ranges are the great débris cones or fans characteristic of the region. The cones from adjacent valleys may coalesce laterally, forming a débris apron along the range. Outward from the range they gradually decrease in elevation and finally merge with the valley bottoms and cease to be recognizable. Many of these cones extend far back into the ranges and in some, like the Beaver Lake Range, nearly bury the mountain.

The deposits of the valleys consist of gravels, sands, and clays. Their depth is unknown, but at several places they have been penetrated by wells to depths of several hundred feet, and there is little doubt that their thickness is to be measured in thousands of feet.

ORIGIN OF THE BASIN RANGES.

The processes by which the physiographic features of the Basin Ranges were formed have been discussed by many investigators, including Gilbert, King, Powell, Dutton, Russell, and more recently by Spurr, Davis, Louderback, Ransome, Lawson, and others, in whose writings the prevailing ideas of the origin of the Basin Ranges and the evidence therefor can be found.

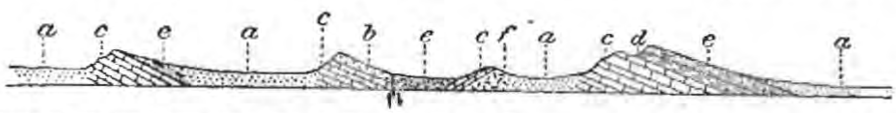


FIGURE 2.—Generalized section through the Mineral, Beaver Lake, San Francisco, and Wah Wah ranges, showing structural relations. a, Recent sediments; b, quartzite; c, limestone; d, shale; e, lava; f, granitic rock.

One of the earliest views formulated was that of Clarence King,[1] who wrote:

> These low mountain chains which lie traced across the desert with a north and south trend are ordinarily the tops of folds whose deep synclinal valleys are filled with Tertiary and Quaternary detritus.

Later King[2] greatly modified his earlier views and came more nearly to agree with Gilbert (see below) as to their manner of origin. J. E. Spurr,[3] however, more recently advanced the belief that the present form of the ranges is due primarily to erosion, a belief in general accordance with the earlier views of King.

Soon after King published his earlier explanation of the origin of the Basin Ranges, Gilbert[4] suggested that the region had been broken, mainly along north-south lines, into blocks that had been tilted at various angles. (See fig. 3.) Gilbert's theory of the origin of the

[1] U. S. Geol. Expl. 40th Par., Final Rept., vol. 3, p. 451, 1870.

[2] King, Clarence, Systematic geology: U. S. Geol. Expl. 40th Par. Final Rept., vol. 1, p. 735, 1878.

[3] Geol. Soc. America Bull., vol. 12, p. 217, 1901.

[4] Gilbert, G. K., Preliminary geological report: U. S. Geog. Surveys W. 100th Mer. Prog. Rept., for 1872, Appendix D, p. 50, 1874.

Basin Ranges has been pretty generally accepted by subsequent observers, with some modifications. In a paper prepared by Dr. Gilbert shortly before his death in 1918 he reached essentially the same conclusion regarding the origin of the Basin Ranges as he did in his earlier paper. Le Conte[1] has suggested that the region was broken into blocks by a subsidence following an uplift, or more probably by

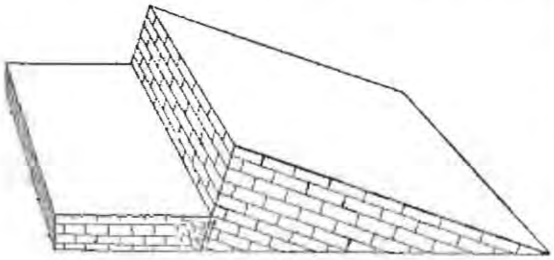


FIGURE 3.—Ideal form of fault blocks disregarding erosion.

a succession of uplifts and subsidences caused by intumescent lava. The writer has offered a similar explanation for the Basin Ranges in southern Utah,[2] where faulting followed the extrusion of a large amount of lava. Louderback[3] has given convincing evidence of fault-block structure in the Humboldt Range in Nevada, the faulting having occurred subsequent to the latest volcanic activity of that region. W. M. Davis[4] has called attention especially to the character of the region previous to the faulting and to the changes in the ranges that may be expected to result from erosion (see fig. 4), and has been able to show[5] that the ranges are in different stages of dissection. (See Pl. III.) Lawson[6] has very clearly described the cycle of erosion in a desert region and the gradual progress of the débris cones up the valleys until in advanced stages they may almost bury the range. To judge from the criteria developed by Davis and by Lawson the least mature and presumably the youngest ranges of Utah, as the Wasatch and Tushar ranges, lie along the eastern boundary of the Basin province, and the more matured forms lie well within it. The younger ranges are distinguished not alone by their physiographic form but by the presence of fault scarps in the Pleistocene sediments along their fronts. Recent earthquake shocks in the region are probably due to movement on some of these faults. A somewhat similar condition seems to obtain on the western side of the Great Basin, and one is led to wonder if the Basin province is and has been expanding at the expense of the more elevated regions on both sides. It should be noted, however, that there are ranges of apparently rather recent origin well within the borders of the Basin province, notably the Humboldt Range described by Louderback.[7]

[1] Le Conte, Joseph, On the origin of normal faults and the structure of the Basin Ranges: Am. Jour. Sci., 3d ser., vol. 38, pp. 257-263, 1889.

[2] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, p. 27, 1913.

[3] Louderback, G. D., Basin Range structure of the Humboldt region: Geol. Soc. America Bull., vol. 15, pp. 289-346, 1904.

[4] Davis, W. M., Harvard Coll. Mus. Comp. Zool. Bull., vol. 42, pp. 129-177, 1903.

[5] Idem, vol. 49, pp. 15-56, 1905.

[6] Lawson, A. C., The epigene profiles of the desert: California Univ. Dept. Geology Bull., vol. 9, no. 3, pp. 23-48, 1915.

EROSION AND SEDIMENTATION.

Subsequent to the formation of the Basin Ranges the principal physiographic features developed have been those due to erosion and

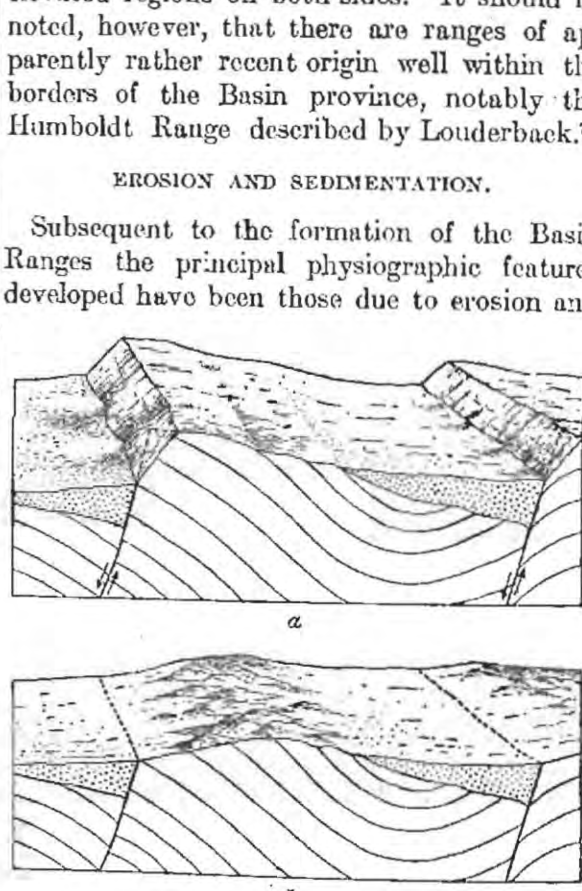


FIGURE 4.—Stereogram showing stages of erosion in fault-block mountains. a, Young stage; b, mature stage. After W. M. Davis.

sedimentation. The valleys in younger ranges like the Wasatch are characteristically of the canyon type, and in older ranges like the Beaver Lake are broad and open. Where the streams pass from the mountain ranges to the flat intermountain areas, alluvial cones have been built.

During the period when a large part of the Great Basin region of the State was occupied by Lake Bonneville, of which Great Salt Lake and

[7] Louderback, G. D., op. cit., pp. 289-346.

other smaller lakes may be regarded as remnants, deltas and various types of shore deposits and wave-cut cliffs were formed.[1] The highest or Bonneville beach is about 1,000 feet above the present level of Great Salt Lake. The Provo beach is about 375 feet lower. Other beaches can be recognized at many localities.

The work of wind as an agent of erosion and transportation is less understood than that of water, and there is considerable difference of opinion concerning its importance. No one familiar with arid regions can doubt its ability to transport sediments, and locally, as Cross[2] has shown, it is an erosive agent of some importance. But the writer's observations have led him to believe that the major features, both of the Basin and Plateau provinces, are the result of water erosion, transportation, and deposition. All the larger physiographic features resulting from denudation are related to features that are clearly the result of the work of waters. Ransome[3] has pointed out the inconsistency and absurdity of considering the wind to have been the dominant cause of the Basin Ranges, and there seems to be little basis for considering it to have been dominant in the Plateau province.

DEVELOPMENT.

Throughout the Mesozoic era, and perhaps into the Cenozoic, most of the Basin province in Utah was undergoing erosion, the sediments being deposited to the eastward in what is now the Plateau province. In post-Cretaceous or early Tertiary time there was a general uplifting of the region, including both the present Basin and Plateau provinces. Accompanying, or closely following, this uplift there was extensive volcanic activity, and following, and possibly accompanying, the volcanic activity there was a partial subsidence, during which the Basin region broke into a series of blocks, which settled unevenly, producing the ridges. This uplift and subsidence need not be supposed to have been two clearly defined events; the relations are far more readily understood if attributed to intermittent uplift, volcanic activity, and subsidence extending over a long period. The relative uplift of the Plateau province was greater than that of the Basin province, or more probably the subsidence in the Basin province was greater than that in the Plateau province. Eventually this relative difference in elevation and subsidence caused the Plateau province to stand at a higher elevation than the Basin province; and differential elevation and subsidence in the Basin province caused the formation of a basin whose lowest portion was considerably below the rim. Whether this differential settling has been in progress over the present area of the Basin province throughout its period of formation, or whether it began within the present boundary and has been gradually progressing outward, is not yet known. As noted (p. 72), the relative immaturity along its borders suggests progression.

As soon as the irregular settling of the blocks had caused some areas to be lower than others agencies of denudation attacked the higher portions, and the resulting detritus was deposited in the lower areas and produced the broad flat intermountain valleys.

The lowering of the Basin province below the Plateau province caused a reversal of the drainage, which had previously been from the Basin region to the Plateau province. The streams began to work gradually back by headwater erosion into the Plateau region. This process has, however, been relatively slow, and the Great Basin drainage has been able to encroach only a few miles on the Plateau region. The slightness of this encroachment, as compared with that of the Colorado drainage (see Pl. I), may be due to two principal causes. First, the Great Basin drainage was probably not initiated till some time after the elevation of the region, whereas that of the Colorado probably had its beginning simultaneously with the initial uplift; and, second, each additional uplift of the region raised it higher above the base-level of the Colorado system (the sea), giving renewed power to that system, whereas the uplift of the Great Basin raised its base-level (the lower portion of the Basin) along with the rest of the region, and gave no additional power to the streams. The only change in base-level for the streams entering the Great Basin has resulted from the relatively greater sinking of the Basin province as compared with the Plateau, and this has been in part balanced by the filling of the basin with sediment, which has tended to raise the base-level.

[1] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, 1890.

[2] Cross, Whitman, Wind erosion in the Plateau country: Geol. Soc. America Bull., vol. 19, pp. 53-62, 1908.

[3] Problems in American geology, p. 341, Yale University Press, 1915.

It is considered by some that the streams that pass from the Plateau region to the Basin region are antecedent—that is, that they have maintained their courses while the mountain ranges were rising across their path. If the development of the region has been correctly interpreted in the preceding paragraphs, this seems extremely unlikely. If, at the beginning of the uplift, the drainage was from the Basin Range province to the Plateau, there was, at the time of the reversal, no drainage westward from the Plateau province to maintain itself. It also seems significant that the Canyon Range, the most notable example of a mountain cut directly across by a river, was probably completely buried by early Tertiary sediments[1] and was gradually uncovered as the stream cut its valley. The Beaver River canyon through the Mineral Range has been developed along a line of faulting and is evidently controlled by the weakness of the rock at that locality and has no connection with preuplift drainage. The Squaw Springs Pass through the San Francisco Range has also developed along a line of faulting. The western drainage has pushed through the range and has captured a small drainage area on the east side of the range. Other canyons of the western slope of the San Francisco Range have pushed far inward toward its eastern margin but have not yet cut completely through. Here the western drainage has a much shorter distance to the same base-level (Sevier Lake) than the eastern and has therefore been able to accomplish much more, and the development of a valley across the range plainly can not be attributed to antecedent drainage. (See fig. 5.) Most of the streams crossing a range that have been noted by the writer may be logically accounted for by normal headward erosion.

An unpublished manuscript on the Basin Ranges by Dr. G. K. Gilbert cites evidence to support the idea that a relative uplift of the area east of the Wasatch Range resulted in a reversal of the drainage before the present Wasatch Mountains were formed, and that that drainage was maintained across this range as it was uplifted.

[1] Loughlin, G. F., Reconnaissance in the Canyon Range of west-central Utah: U. S. Geol. Survey Prof. Paper 90, p. 58, 1914.

CORRELATION OF THE GREAT BASIN WITH THE OTHER PROVINCES.

With the data at present available it is not possible closely to correlate the later physiographic development of the Basin province of Utah with that of the provinces to the east. The several striking stages of erosional development that have been recognized to the east are either absent in the Basin province or if present are so modified that they have not been recognized. A careful determination and correlation of the late physiographic developments within and without the Basin drainage promises most interesting and important results. The rather meager observations of the writer suggest that development has been very different within and without the Basin. Outside the Basin every elevation or depression of the region has changed the elevation relative to the base-level, and the consequent renewal or retardation of the work of the streams has found expression in the physiography. Inside the Basin such elevations and depressions have not changed the elevation relative to the base-level; the streams have therefore not been rejuvenated, and the physiographic development has been more uniform. The results due to climatic changes both within and without the Basin are probably nearly uniform in the more elevated portions. The results in the lower portions, however, are markedly different; outside the Basin a change in precipitation simply affected the size of the streams, which flowed freely to the sea; whereas within the Basin it affected the areas of the lakes.

GEOLOGY.

STRATIGRAPHY.

The stratigraphy of Utah is so complex that its complete discussion would require space far in excess of that available. The attempt here is merely to outline the major features and prepare a general setting for the more detailed discussions devoted to the several districts.

GEOLOGIC MAP.

The topographic base map (Pl. I), on which the geology has been platted, was compiled for the most part from the older topographic

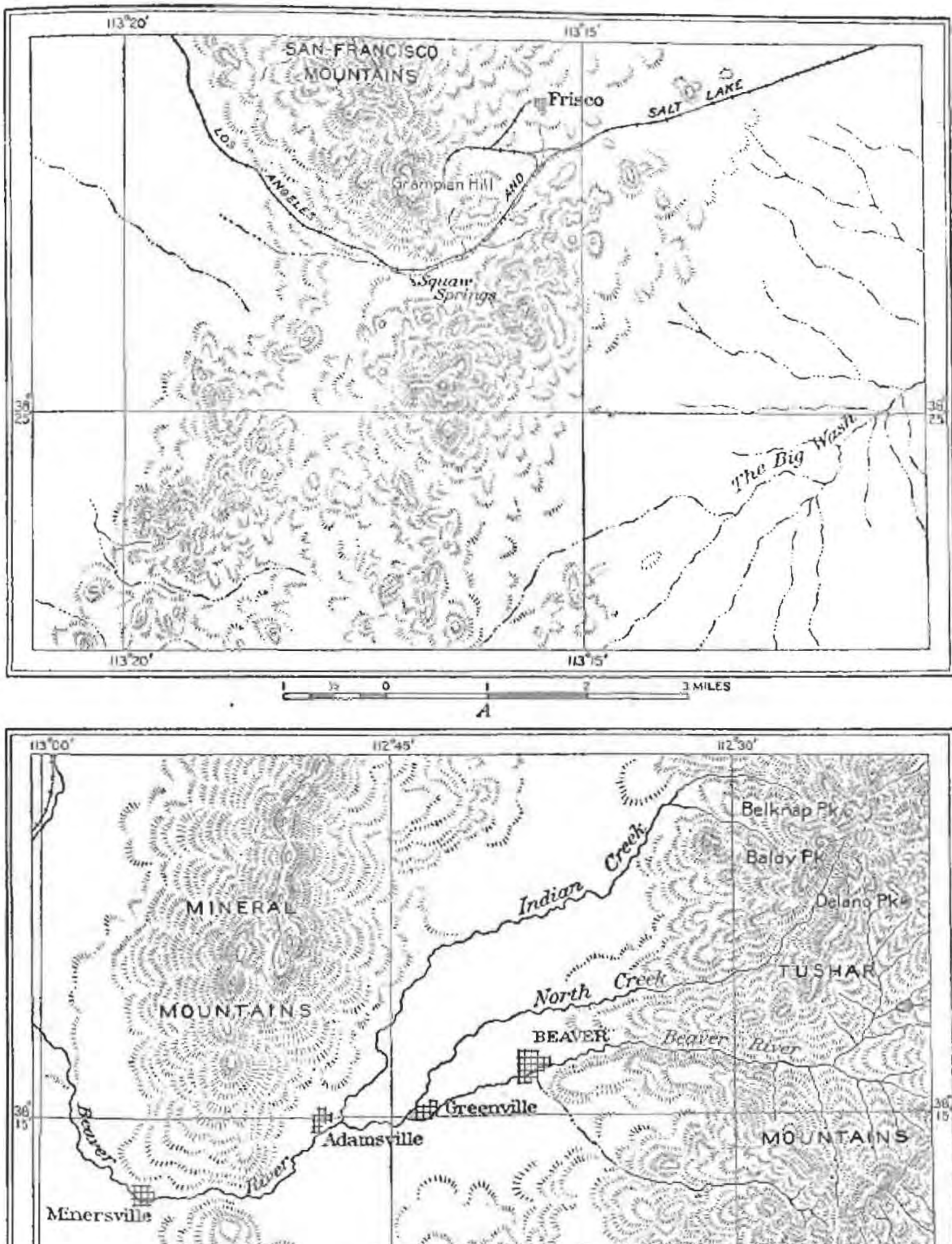


FIGURE 5.—*A*, Squaw Springs Pass. Headwater erosion has developed a valley through the range. (From Frisco special topographic map.) *B*, Beaver Canyon, Mineral Range. The stream has developed a valley through the range and has acquired a large drainage area beyond. (From Beaver topographic map.)

maps of the United States Geological Survey, on the 1:250,000 scale, now issued as reconnaissance maps. These maps leave much to be desired in the way of detail and accuracy, but they give a fair idea of the topography of the region and are of great value in the absence of better maps. The small-scale map compiled from them naturally inherits their imperfections but nevertheless gives a better idea of the relations of geology to topography than a map without contours.

The geologic map (Pl. IV) has been compiled from many sources and includes considerable unpublished material kindly furnished by members of the Geological Survey. The material used differed widely in accuracy, ranging from large-scale maps of mining districts on which the formations have been outlined with great care to reconnaissance sketches based in part on long-range observations. It is hoped that the users of the map will keep this in mind. The material used includes the maps made by the Wheeler, Hayden, and Fortieth Parallel surveys; those of Gilbert, Dutton, Powell, White, Eldridge, and Gregory; mining maps of several districts in the State, including those by Spurr, Boutwell, Leith and Harder, Tower and Smith, and Lindgren and Loughlin; maps of coal and oil regions by Richardson, Gale, Wegemann, Woodruff, Lupton, and Clarke; and maps of the phosphatic deposits by Richards, Mansfield, Blackwelder, and Schultz. Messrs. Schultz and Lupton have furnished data from unpublished reports, the former for the region around the Uinta Mountains, and the latter for that around the San Rafael Swell. Most of the mining districts of the State have been visited by the writer or by Mr. Loughlin, and such stratigraphic information as was collected has been incorporated in the map. Additional data concerning local areas have been obtained from many other sources.

The units of representation chosen have been geologic systems rather than formations, for two reasons: First, it is desired to keep the map as simple as possible in order that the general features may not be hidden in a mass of detail; and second, the information necessary for a consistent mapping by formations throughout the State does not yet exist.

Under the pre-Cambrian are included areas of schists and quartzites that are unquestionably older than the known Cambrian. It is probable that some of the quartzite included under the Cambrian will eventually be shown to be pre-Cambrian, but the separation has been made in only a few places and the regional separation requires further study.

Under Cambrian are included all the sediments known to be of that age and, as already noted, some quartzites that are probably older.

Under Ordovician and Silurian are included the strata known to be of those ages.

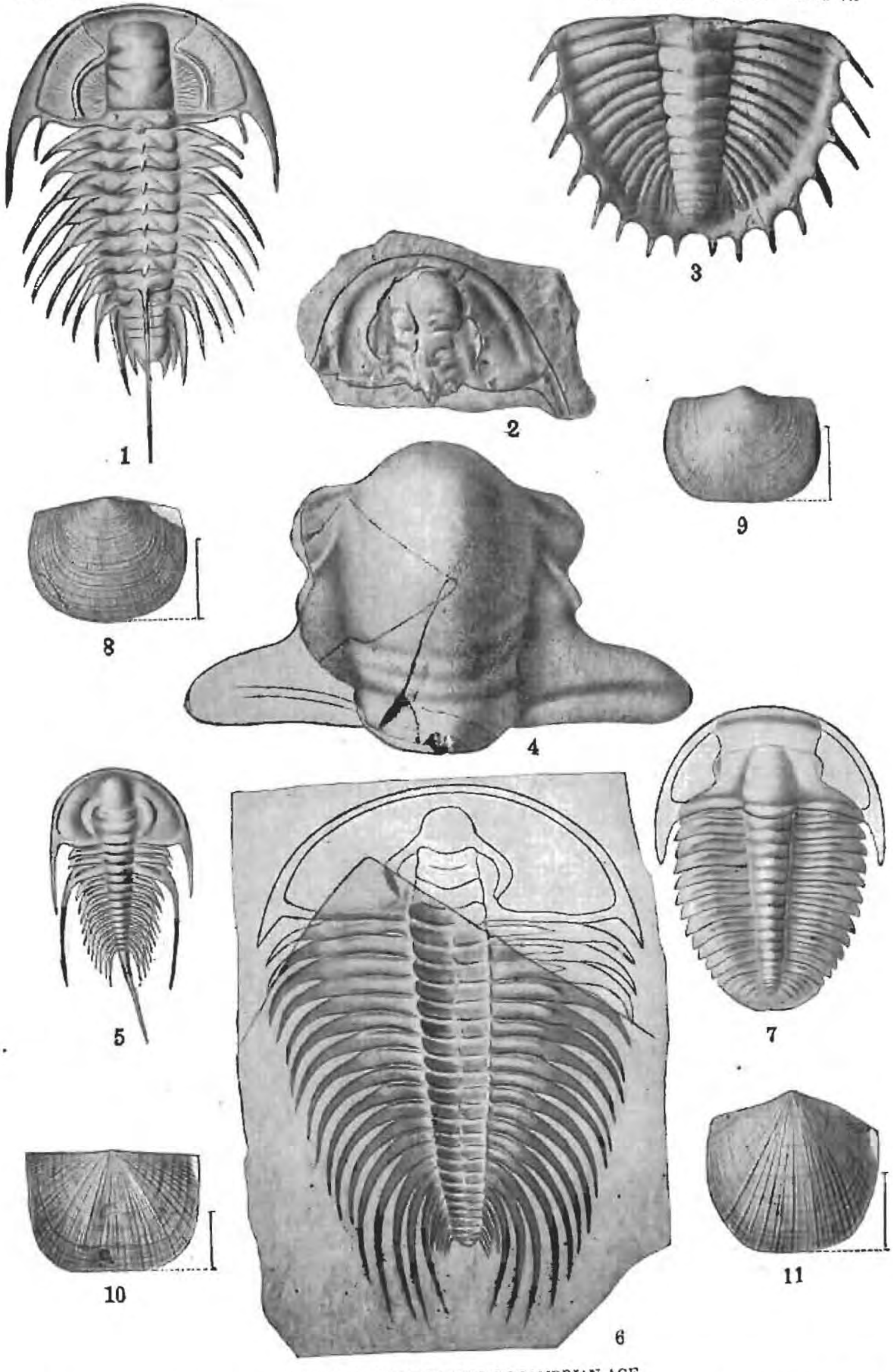
Under Carboniferous are included all the known Carboniferous rocks, but not the "Permo-Carboniferous" of earlier surveys.

Under the Triassic are included the Triassic of the recent maps and the "Permo-Carboniferous" of some of the older maps. Study of the fossils in the phosphate fields of Idaho, Wyoming, and Utah in recent years has led to the assignment to the Triassic of the strata previously designated "Permo-Carboniferous"; and as the "Permo-Carboniferous" beds of southern Utah contain the same fossil forms they are also assigned to the Triassic.

The upper boundary of the Triassic in southern Utah is placed at the bottom of the White Cliff sandstone of Powell and Dutton, which is considered (though not proved) to be equivalent in whole or part to the La Plata sandstone of western Colorado. In Utah no convincing evidence that this is the boundary between Triassic and Jurassic has been discovered, but in Colorado an unconformity found by Cross at the base of the La Plata seems to warrant making this dividing line. Around the Uinta Range there has been little detailed mapping separating the Jurassic and Triassic, and their distribution as shown on the map is largely an arbitrary division of the area covered by the rocks of those systems.

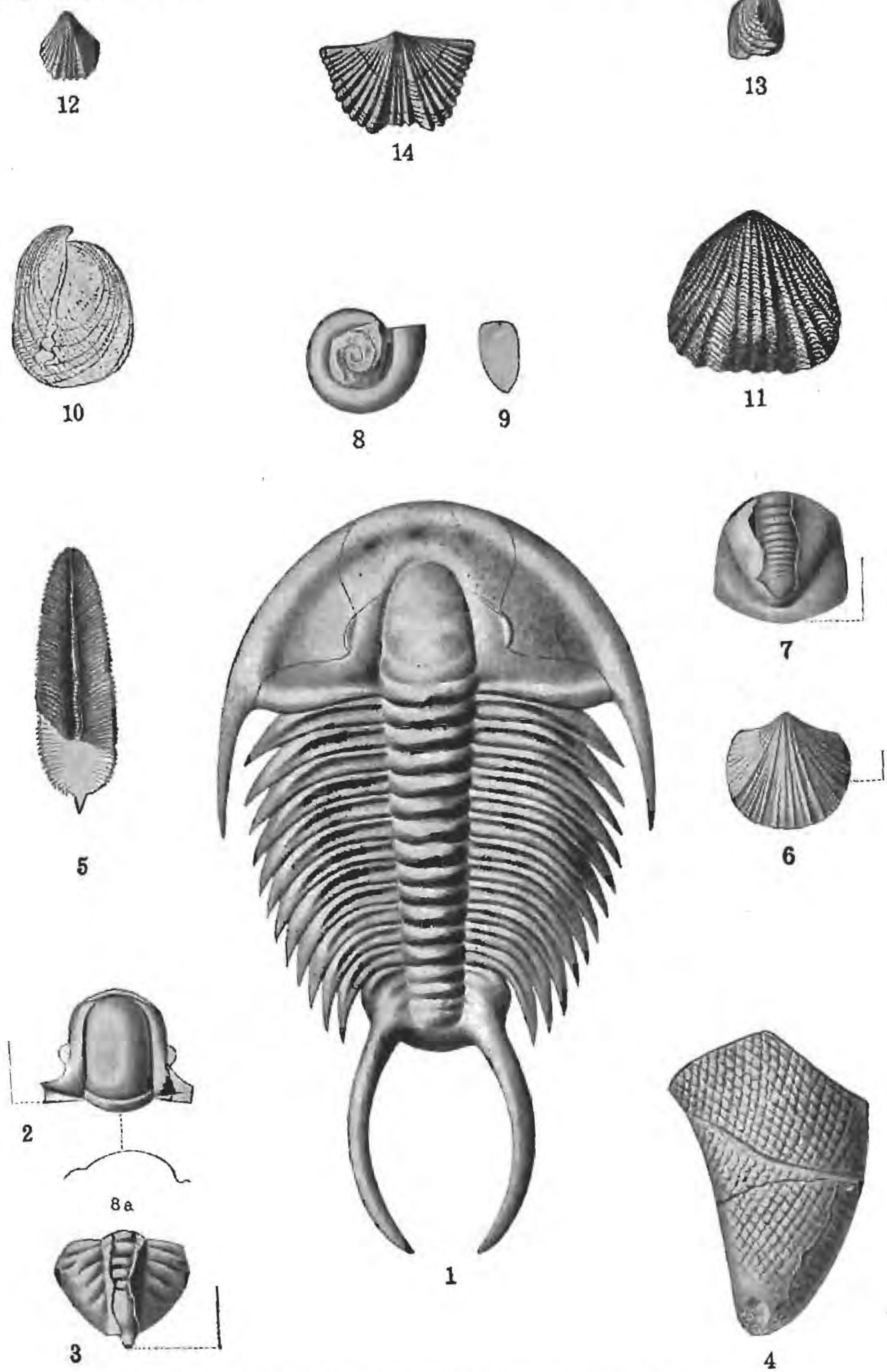
The Jurassic includes the rocks from the base of the White Cliff sandstone to the base of the Dakota sandstone. The upper portion includes the McElmo formation, equivalent to the "Lower Dakota" of the Hayden survey in Utah and approximately equivalent to the Flaming Gorge of Powell, Gilbert, and Dutton.

There is no general agreement among geologists as to the separation of the Jurassic and Cretaceous. On the map all the red and variegated beds above the White Cliff sandstone are shown as Jurassic. It is recognized by many geologists and strongly contended by some that



CHARACTERISTIC FOSSILS OF CAMBRIAN AGE.

1, Zacanthoides typicalis Walcott; 2, Holmia rowei Walcott; 3, 4, Neolenus inflatus Walcott; 5, Mesonacis gilberti Meek; 6, Nevadia weeksi Walcott; 7, Ptychoparia kingi Meek; 8, 9, Eoorthis newberryi Walcott; 10, 11, Billingsella coloradoensis (Shumard).



CHARACTERISTIC FOSSILS OF CAMBRIAN AND ORDOVICIAN AGE.

1, Cambrian; 2-14, Ordovician. 1, Crepicephalus texanus (Shumard); 2, 3, Holasaphus congeneris (Walcott); 4, Receptaculites ellipticus Walcott; 5, Phyllograptus loringi White; 6, Orthis hamburgensis Walcott; 7, Asaphus? curiosus Billings; 8, 9, Maclurea subannulata Walcott and sections of outer whorl of same; 10, 11, Rhynchotrema capax (Conrad); 12, 13, Rhynchotrema argenturbica (White); 14, Platystrophia sp.

the Cretaceous may include the McElmo formation, in which case it extends down to the marine Jurassic shales, which in Utah extend for only a few hundred feet above the White Cliff sandstone. In recent years, however, the United States Geological Survey has called these rocks questionable Jurassic, and this usage is followed in this report. The reader should clearly recognize, however, the uncertainty as to the age of these rocks.

Under Cretaceous are included the formations from the base of the Dakota sandstone to the Tertiary.

Under Tertiary are included all sedimentary formations so mapped in reports on the State.

Under Quaternary are included the valley fillings between the basin ranges, the unconsolidated deposits along some of the larger streams, and other areas of recent débris, where it buries the earlier rocks.

Under extrusive rocks are included all flows, tuffs, breccias, and other igneous rocks of whatever age or composition that reached the surface before solidifying. For the most part they are Tertiary.

Under intrusive rocks are included all post-Paleozoic rocks that solidified below the surface and were later exposed by erosion. Small areas of pre-Cambrian intrusives have not been differentiated from other pre-Cambrian rocks.

Geologic sections in the several districts of the State are assembled and correlated on Plates V and VI, in pocket.

FOSSILS.

Plates showing some of the fossils respectively characteristic of Paleozoic eras and of the Triassic and Jurassic periods have been prepared by the paleontologists of the Survey and will, it is hoped, assist the mining men of the State to determine the age of the rocks in which they are working. (See Pls. VII to X and LII to LVII.)

It is perhaps needless to say that persons not trained in the determination of fossils will find difficulty in recognizing the different forms, and certainly caution should be observed in basing age determination on a single specimen. But it is believed that the layman will generally be able readily to determine from which of the major divisions a collection of fossils has been derived.

SEDIMENTARY ROCKS.

PRE-CAMBRIAN ROCKS.

The pre-Cambrian rocks include some granite but consist mainly of schists, quartzites, and slates, all more or less metamorphosed. Locally, at least, as in Big and Little Cottonwood canyons, tillite is an important and interesting member of the series. In general, the lower members are the most highly altered. The schists, as those of Browns Park in the Uinta Range, have been generally regarded as Archean; and the members immediately underlying the Cambrian in the Big Cottonwood region are pretty certainly Algonkian.

The boundary between the Cambrian and Algonkian rocks has been determined in but few places in the State. Blackwelder, Hintze, and others have located it from American Fork and the Cottonwoods northward to Brigham, and it seems highly probable that future studies may differentiate the great quartzite-slate-shale series at other localities.

Little is known regarding the thickness of the series. (See Pls. V, VI.) In the Big Cottonwood Canyon 10,000 to 11,000 feet of Algonkian strata are exposed. To the north the upper members have been removed by erosion and in places the Cambrian rests directly on the Archean. In other parts of the Cordilleran region the Algonkian rocks show great thickness and more varied character than in Utah. Walcott[1] says:

> In Arizona the Algonkian period of sedimentation is represented by nearly 12,000 feet in thickness of sandstone, shale, and limestone of the Grand Canyon group. In Utah and Nevada sediments forming only sandstone and siliceous shale appear to have gathered, while in Montana there is a development of limestone 4,800 feet in thickness in addition to nearly 20,000 feet of siliceous and arenaceous beds.

The most extensive area of pre-Cambrian in the State is along the front of the Wasatch Range, where it is present from a point near Willard to Centerville and again near the Cottonwood canyons. It also forms Fremont and Antelope islands in Great Salt Lake and probably the western portion of Promontory Point. The pre-Cambrian makes up a large part of the ranges between the Tintic and

[1] Walcott, C. D., The Cambrian and its problems in the Cordilleran region: Problems in American geology, p. 165, Yale University Press, 1915.

Thomas ranges, and farther to the west small areas of schist are exposed in the Granite and Deep Creek ranges. In the northwestern part of the State the pre-Cambrian is present in the Raft River and Grouse Creek mountains. In the eastern Uinta Mountains the pre-Cambrian is exposed north of Browns Peak in the vicinity of Red Creek and for several miles to the east and west, and a part of the great quartzite series of the range is probably pre-Cambrian. It is also exposed in some of the valleys near the Colorado State line north of the Denver & Rio Grande Railroad. A small exposure of pre-Cambrian in the extreme southwestern corner of the State in the Beaver Dam Mountains is a portion of a larger area in Arizona and Nevada.

CAMBRIAN SYSTEM.

DISTRIBUTION AND CHARACTER.

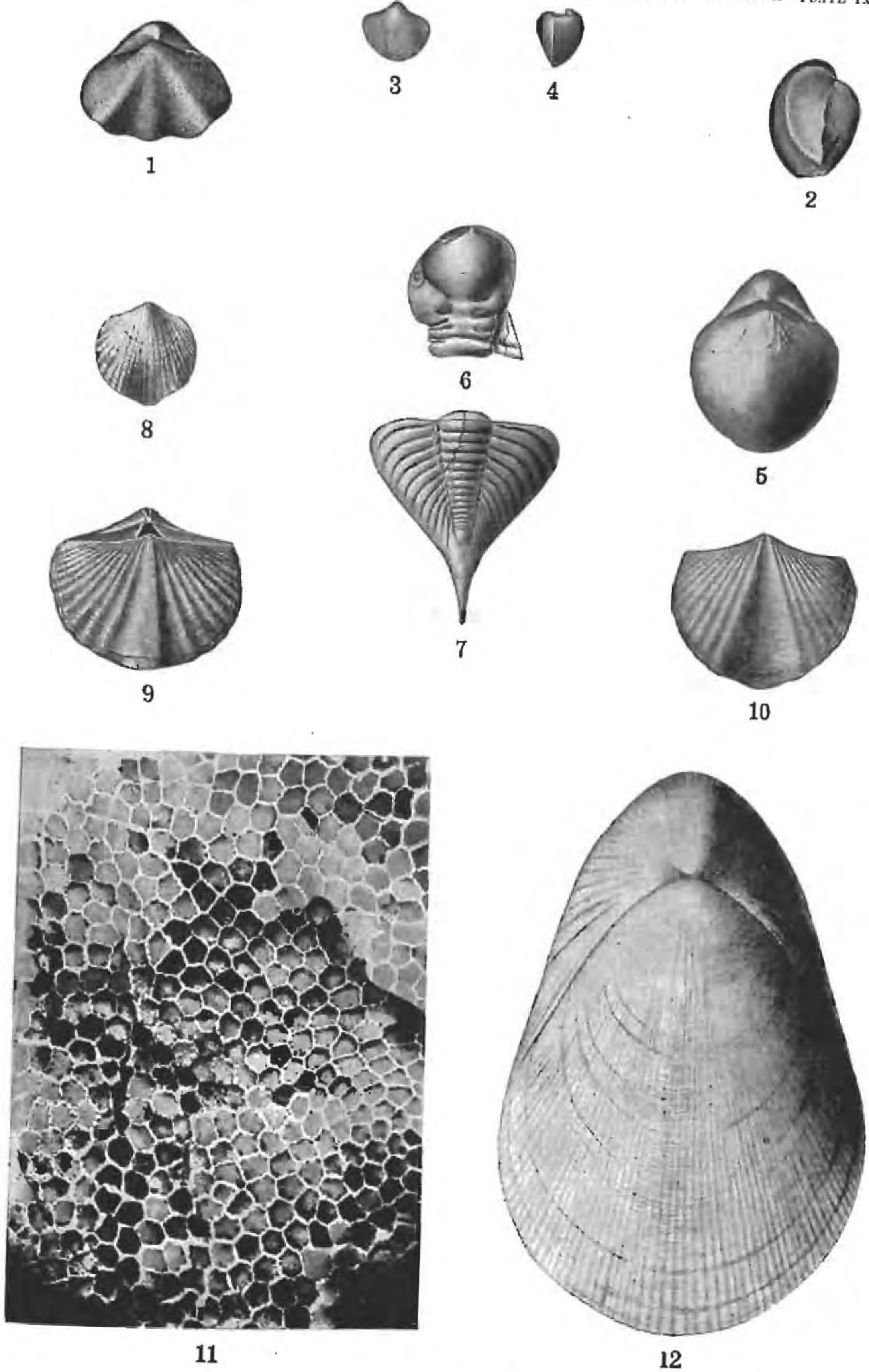
Cambrian rocks are widely distributed in western Utah. They lie at the western base of the Beaver Dam Mountains in the extreme southwestern corner of the State. Farther north they form the Wah Wah Range, part of the San Francisco-Beaver Creek Range, a large part of the House Range and of the southern part of the Thomas Range. Still farther north they are present in the southern portion of the Deep Creek Range and in the Simpson, Tintic, Stansbury, and Oquirrh ranges. They are exposed in the Wasatch Range at several places from Mount Nebo northward. In the extreme northwestern part of the State Cambrian rocks are present in the Raft River Range. In the northeastern part of the State the central plateau of the Uinta Range is probably principally Cambrian, though older rocks may be exposed in the canyons. (See Pl. V, in pocket.) Certain fossils that are characteristic of Cambrian rocks and by which they may be identified are shown in Plate VII.

The character of the Cambrian varies somewhat from place to place, but everywhere the early Cambrian is composed mainly of quartzite and sandy shale and the later Cambrian mainly of limestone. The thickness of the Cambrian differs greatly in different parts of the State. Along the eastern border of the State, north of the La Sal Mountains and in adjacent parts of Colorado, the Cambrian is entirely lacking and along the southern border and in adjacent portions of Arizona it is represented by only a few hundred feet of quartzite and shale. In western and northern Utah, on the other hand, its thickness is thousands of feet—in the House Range more than 9,000 feet are exposed.

Although close correlation is not possible where the formations can not be traced from one range to another, nevertheless certain formations are so characteristic that they are readily recognized over wide areas, and, though they may not everywhere represent precisely the same horizon, their recognition aids greatly in understanding the geology. (See Pls. V, VI, in pocket.)

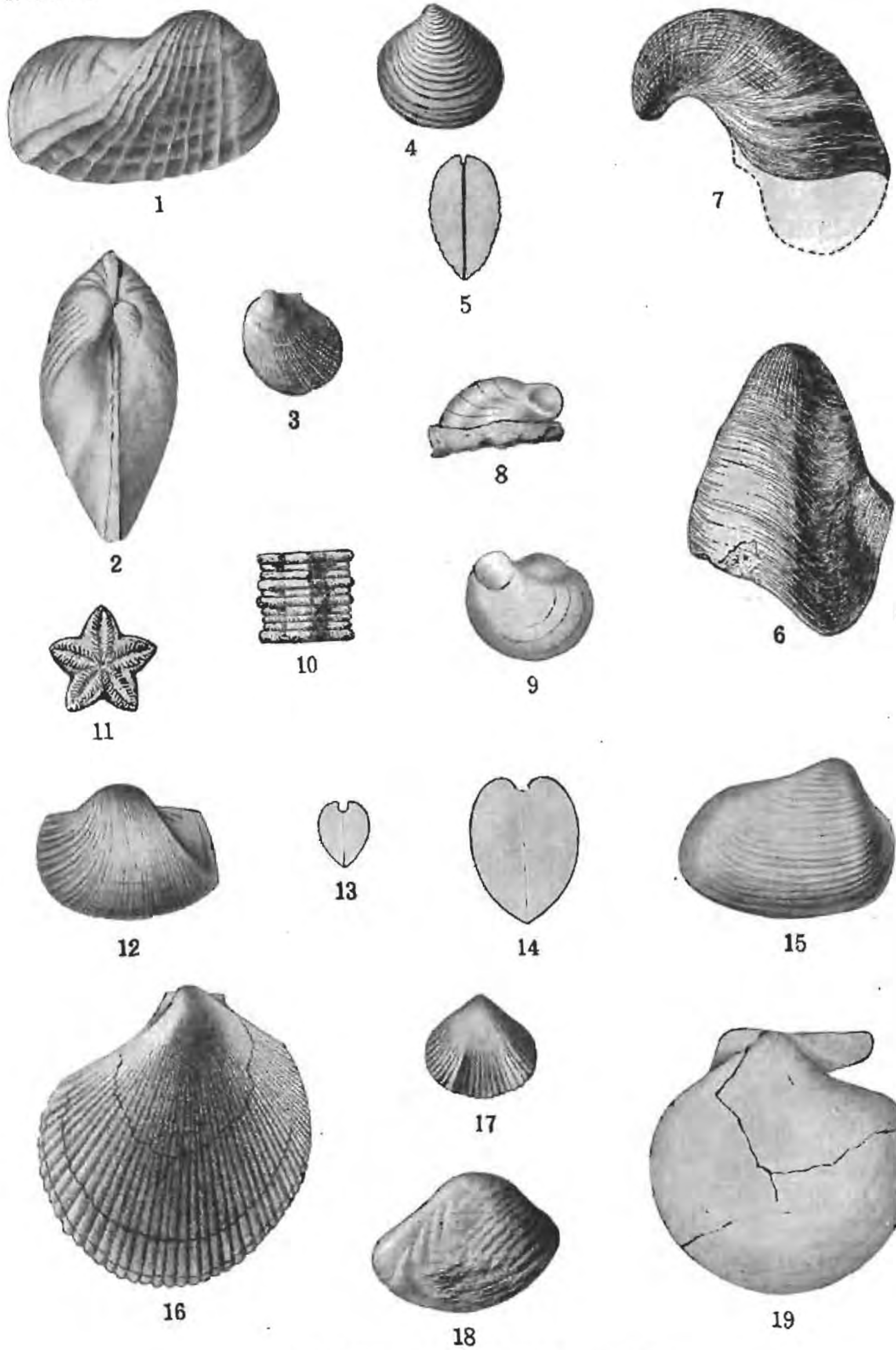
EARLY CAMBRIAN QUARTZITE.

The lowest formation of the Cambrian is a massive quartzite that is probably several thousand feet in thickness in many localities. Its exact thickness, however, is known in but few places, for in but few has it been separated from the Algonkian. In Big Cottonwood Canyon, where the boundary has been determined, the thickness of the Cambrian quartzite is given by Hintze as about 700 or 800 feet. In the Tintic Mountains, however, over 6,000 feet of quartzite is exposed, in which no Algonkian has been recognized, though Mr. Loughlin states (p. 398) that the lower portion may prove to be pre-Cambrian. The quartzite has been given different names in the different ranges, as Tintic quartzite, in the Tintic Range; Brigham quartzite, in the northern Wasatch Range; "Weber" quartzite, in the Uinta Mountains; and Prospect Mountain quartzite in the House Range, where it is correlated with the Lower Cambrian quartzite of the Eureka district, Nevada. The quartzite is present over so wide an area in Utah, has so strong a lithologic similarity at different localities, and everywhere lies so nearly, though probably not exactly, at the same horizon, that it seems desirable for the purposes of the present paper to call it by a single name. The Tintic Mountains, where it is well exposed and where its relations to the overlying formations have been carefully worked out, is rather central for the State and is well known to those interested in mining, and therefore readily comparable with less well known districts. It is therefore suggested that if a single name is desired Tintic quartzite may well be chosen. The quartzite is present in the Tintic Range; at



CHARACTERISTIC FOSSILS OF SILURIAN AND DEVONIAN AGE.

1-10, Devonian; 11, 12, Silurian. 1, 2, *Pentamerus latis* Walcott; 3, 4, 5, *Martinia maia* (Billings); 6, 7, *Dalmanites meeki* Walcott; 8, *Atrypa reticularis* (Linnaeus); 9, 10, *Spirifer pinonensis* Meek; 11, *Favosites favosus* Goldfuss; 12, *Conchidium decussatum* Whiteaves. Figures 3 and 4 represent young shells.



CHARACTERISTIC FOSSILS OF JURASSIC AGE.

1, 2, Pholadomya kingii Meek; 3, Pseudomonotis (Eumicrotis) curta (Hall); 4, 5, Astarte packardi White; 6, 7, Gryphaea calceola var. nebrascensis Meek and Hayden; 8, 9, Ostrea strigilecula White; 10, 11, Pentacrinus whitei Clark; 12, 13, Cucullaea haguei Meek; 14, 15, Pleuromya subcompressa Meek; 16; Lima occidentalis Hall and Whitfield; 17, Rhynchonella myrina Hall and Whitfield; 18, Trigonia quadrangularis Hall and Whitfield; 19, Camptonectes stygius White.

Ophir in the Oquirrh Range; in the Mount Nebo Range; in the central and northern Wasatch Range; probably in the Raft River Range; in the Promontory Range; the Stansbury Range; the Simpson Mountains; the southern part of the Thomas Range; the House Range; the Deep Creek Mountains; and the Wah Wah Range.

It is possible that the lower quartzite and shales (Tonto group) exposed in the Beaver Dam Mountains and in northern Arizona are to be correlated with this quartzite, though the data at present available do not warrant such a correlation, for the Tonto group appears to be the younger. No fossils have been found in this quartzite, but at several localities it is overlain, apparently conformably, by fossiliferous shale of Lower (?) and Middle Cambrian age, indicating that for the most part it is Lower (?) Cambrian, though in some localities its upper part may be Middle Cambrian.

OPHIR FORMATION.

Overlying the early Cambrian quartzite is a series of shaly sediments, commonly including some calcareous beds and in places some well-defined strata of limestone, the whole overlain by the more massive Cambrian limestones. These shaly beds overlying the quartzites[1] are present nearly everywhere. They range in thickness from not more than 100 feet to several hundred feet. They contain Middle Cambrian fossils practically everywhere and, in the House Range, at Ophir, and in Big Cottonwood Canyon, supposed Lower Cambrian forms also. In most of the localities examined by the writer where only Middle Cambrian fossils have been found, lower shales are present that may represent the Lower Cambrian. In the northeastern part of the State, however, Middle Cambrian shales apparently rest directly on the quartzite, and it seems possible that they lie at a slightly higher horizon than in the western part of the State.

In certain localities and ranges, such as the Bear Lake region and the House Range, these shales and limestones have been divided into several formations, which, however, can probably not be recognized throughout the region. The series as a whole, however, is characteristic, easily recognized, and widely distributed. Where it is not divided the name Ophir formation is adopted for it, as it is well exposed in the Ophir district, where it contains large deposits of ore. The name Alta shale has been proposed by F. F. Hintze for this series in the Cottonwood region, but as that name had previously been adopted for another formation it is not available, though otherwise appropriate and desirable.

The Ophir formation is represented in practically all the ranges in which the early Cambrian quartzite occurs.

LATER CAMBRIAN ROCKS.

The Cambrian sediments lying above the shaly series in the different ranges are somewhat varied in character, and sufficient data are not available for their definite correlation. Prevailingly they are limestones and dolomites. The sections (Pls. V, VI) show marked variations in the thickness of the Cambrian rocks above the Ophir formation. How far the differences in thickness are due to erosion, which is known to have taken place before the Mississippian period, and how far to nondeposition can not now be positively stated.

Readers who are interested in geologic conditions in the Cordilleran region during Cambrian time, so far as they have been ascertained, are referred to Walcott's paper on the subject.[2]

ORDOVICIAN AND SILURIAN SYSTEMS.

The Ordovician and Silurian deposits are grouped together (see Pl. IV, in pocket) because in many of the ranges sufficient detailed work has not been done to determine the boundary between the two. In many places, too, the boundaries between the Cambrian and Ordovician and between the Silurian and Devonian have been only approximately determined.

In western Utah the Ordovician and Silurian rocks are widely distributed and seem to be present in most places where the systems above and below are exposed. They have been recognized in the San Francisco, House, Deep Creek, Fish Springs, Tintic, Lake Side, Silver Islet, northern Wasatch, and Bear River ranges, and are probably present in the Promontory Range. In eastern Utah, however, where erosion has exposed the pre-Paleozoic rocks, and in the

[1] Howell, E. E., Geology of portions of Utah, Nevada, Arizona, and New Mexico: U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, p. 244, 1875.

[2] Walcott, C. D., The Cambrian and its problems in the Cordilleran region: Problems of American geology, Yale University Press, 1915.

extreme southwestern part of the State, they have not been recognized, though more detailed work may reveal them in the Beaver Dam Mountains. They are absent from the Cottonwood district, where they were removed by pre-Mississippian erosion. (See Pls. V, VI.)

The Ordovician and Silurian sediments are in large part calcareous and dolomitic, the dolomitic deposits being especially important. They include, however, an important quartzite member in both the northern and the southwestern parts of the State, though this appears to be lacking in the Tintic Range.

In northern Utah the Ordovician and Silurian beds reach a thickness of 3,000 feet according to Richardson; and in southwestern Utah they probably attain as great or greater thickness. In both sections of the State the lower beds are limestone and dolomites overlain by quartzite, which in turn is overlain by more limestone and dolomites. Certain fossil forms that are characteristic of the Ordovician and Silurian and by which they may be identified are shown in Plates VIII and IX.

DEVONIAN SYSTEM.

Devonian sediments have been recognized in northern Utah, in the Wasatch and Bear River ranges, in the Bear Lake region, in the central Wasatch Range, in the Tintic Range, and in the Star Range in Beaver County, and they are probably present in other ranges in western Utah. (See Pl. IV, in pocket.)

The Devonian sediments are prevailingly calcareous and dolomitic, the dolomitic deposits predominating. (See Pls. V, VI.) In the Bear Lake region Richardson has described 1,400 feet of prevailingly dolomitic Middle to Upper Devonian. In the northern Wasatch E. M. Kindle found 2,250 feet of Devonian, and in the central Wasatch F. F. Hintze found Devonian fossils in rocks overlying Cambrian. In the Tintic Range the Devonian is unconformably overlain by the Carboniferous rocks, and only a few hundred feet of it has been preserved. In the Star Range the known Devonian consists of about 50 feet of fossiliferous calcareous shale conformably overlying massive limestone and dolomite and underlying similar rocks in which no fossils have been found. As the fossiliferous beds are Upper Devonian, it is highly probable that some of the underlying beds and possible that some of the overlying are Devonian. (For fossil forms characteristic of the Devonian, see Pl. IX.)

CARBONIFEROUS SYSTEM.

Sediments of Carboniferous age are the most widely distributed and are probably the most extensive and the most important economically of any within the State. (See Pl. IV.)

In western Utah Carboniferous rocks are present in all the ranges where erosion has not removed them together with all later rocks. In eastern Utah Carboniferous rocks are exposed in all localities where erosion has cut through the later formations except in some small areas near the Utah-Colorado boundary south of the Denver & Rio Grande Railroad, where the Mesozoic rocks rest directly on the pre-Cambrian.

Carboniferous sediments were deposited over nearly all and probably all of the State, and their present absence from certain areas is due to erosion. Over much of eastern Utah they are buried beneath many hundreds of feet of later sedimentary and volcanic rocks, but there is little doubt of their presence beneath these rocks.

The thickness of the Carboniferous deposits differs at different localities. (See Pls. V, VI.) In the Star Range in Beaver County about 3,000 feet of Carboniferous sediments are present and in the extreme southern part of the State and adjacent parts of Arizona similar thicknesses occur. In the extreme northern part of the State Richardson found about the same thickness. In the Uinta Range Powell and Weeks each found a somewhat greater thickness. In the central Wasatch Range the thickness of the Carboniferous series probably attains 4,000 feet. In the Tintic mining district only the lower Carboniferous or Mississippian, amounting to about 2,000 feet, is present. In the northern part of the Tintic Range, however, the system attains a great though unmeasured thickness. Its greatest thickness is attained in the Oquirrh Range, where it appears to be several times as great as in any other locality in the State. The whole range has never been studied in detail, and it is possible that future work may show considerable duplication by faults, though there can be little doubt that the Carboniferous is unusually thick and that the Devonian,

Silurian, and Ordovician, if present at all, are very thin. In eastern and southeastern Utah the formations underlying the Carboniferous have not been exposed except along the Utah-Colorado boundary south of the Denver & Rio Grande Railroad, where the Mesozoic sediments rest upon the pre-Cambrian. It seems probable that the Carboniferous thins in this part of the State, though no definite data are available.

The lower Carboniferous (Mississippian) sediments in all parts of the State are prevailingly limestones. The later Carboniferous rocks contain much sandstone and quartzite and are prevailingly sandy in many localities, as in the Wasatch and Oquirrh ranges, where the Weber quartzite (Pennsylvanian) is strongly developed, and farther south and east, where the Pennsylvanian rocks form an important part of the Carboniferous. One persistent horizon approximately at the transition from lower to upper Mississippian is characterized by two or three beds of coarse-grained bluish-gray limestone that carry important ores in districts south of the Cottonwoods in the Wasatch and Oquirrh ranges. In southeastern Utah the Carboniferous sediments are not very deeply exposed, but so far as known they contain much sandy material. Phosphate beds occur persistently in the Park City formation, which is of Pennsylvanian and Permian age.

Fossil forms characteristic of the Carboniferous are shown on Plates LII to LVI (pp. 650–655).

TRIASSIC SYSTEM.

Rocks regarded as Triassic (see Pl. IV) are confined to the eastern, central, and southern parts of the State. The only typical basin ranges in which Triassic rocks have been recognized are the Mineral and Star ranges in Beaver County. Triassic rocks are doubtless present in all parts of eastern Utah where erosion has not cut the surface to lower formations, though over a large part of the area they are buried beneath later formations. Along the southern border of the State and in northern Arizona the removal of later rocks has exposed large areas of Triassic. In southeastern Utah the Colorado River has everywhere cut down to and in places through the Triassic. (See Pls. V, VI.)

Several of the "uplifts" in southeastern Utah have so elevated the Triassic rocks that the erosion surface has reached and in places passed below them. In the Circle Cliffs (Burr Flats) and Miners Mountain (Rabbit Valley) domes along the Water Pocket flexure, in the broad anticline west of the Comb Wash flexure, in the San Rafael Swell, around the Uinta anticline, and along the Wasatch Range the Triassic is exposed.

Triassic rocks appear to have their greatest development in the western part of the exposed areas. In the San Francisco Range 5,000 feet is exposed. At Le Verkin Canyon, according to Huntington and Goldthwaite, 3,800 feet is present. In the Henry Mountains region, according to Gilbert, a thickness of 1,230 feet is present. In the San Rafael region probably not more than 1,500 feet occurs. In the eastern Uinta region Powell ascribes a thickness of 1,600 feet to beds that are probably Triassic. In the Wasatch Range Boutwell finds a thickness of 3,500 feet.

The rocks of the southeastern part of the State supposedly Triassic are readily separated into two divisions, the lower division being designated "Shinarump group" by Powell, Dutton, and others, and the upper division called Vermilion Cliff sandstone by the early workers in the region.

The lower division consists mainly of red and chocolate-colored shales and shaly sandstone, beds of gypsum, and near the base some limestone. Within it is the Shinarump conglomerate, a stratum of conglomerate and sandstone that is present over large areas and that reaches a maximum thickness of perhaps 200 feet. It is particularly conspicuous as a bench and cliff forming rock. Lenticular beds of fine conglomerate and sandstone are present at different horizons in the upper part of the shales, and at any given locality it is sometimes difficult or impossible to tell whether one or any of them is the true Shinarump conglomerate. The sandstone members are commonly light gray and distinctly lighter colored than the shales. They are of particular interest economically, for it is in them that the silver, copper, and uranium deposits in the Triassic beds are found.

In many places the sandstone layers contain rather abundant plant remains, which range in character from reeds to large trees, and some of which have been almost entirely silicified. At other places carbonized material is rather plentiful. In the Circle Cliffs (Burr Flats)

region many stumps in which carbonization is very pronounced and silicification relatively slight were observed in a red shale underlying a lens of sandstone in which almost wholly silicified tree trunks are numerous and within restricted areas are abundant. Similar though perhaps less pronounced differences in the alteration of fossil plants were noted farther north along the Water Pocket fold southward from Fruita.

As already noted, the early workers in the region regarded this lower division as a single group—the "Shinarump." Later C. D. Walcott found "Permo-Carboniferous" fossils in the limestone near the base of this group. He also recognized an unconformity at the base of the Shinarump conglomerate which he interpreted as marking the boundary between the Triassic and older formations. Since then the Shinarump conglomerate has generally been regarded as the basal division of the Triassic, and the portion below has been classed as "Permo-Carboniferous."[1] In recent years, however, extended paleontologic study of the supposed "Permo-Carboniferous" rocks of northern Utah and adjacent regions has led to the conclusion that they are of Lower Triassic age. Similar rocks in southern and southeastern Utah are essentially the same paleontologically and are also now assigned to the Triassic. (For fossil forms characteristic of the Lower Triassic, see Pl. LVII, p. 656.)

The upper formation of the Triassic, as determined by Dutton for the Plateau region, is the Vermilion Cliff sandstone. Dutton says:[2]

> The contact with the shales below is usually conformable, but in the vicinity of the Hurricane fault, where the whole Triassic series is displayed, the junction is often unconformable. The separation, however, of the Trias into an upper and lower series, so far as southern Utah is concerned, is based upon lithological grounds chiefly. It is also a matter of great convenience to effect this separation, since each division has its own topography, and their distributions differ notably. There is, also, a decided contrast in their respective aspects, and the geologist who studies them in the field is constantly reminded of the distinctions. The Upper Trias consists of many beds of sandstone with shaly partings. Usually the component members do not attain great thickness, but a few of them occasionally have a thickness exceeding 200 feet. Very many of them are cross-bedded in a beautiful manner, and although this feature is not so strongly marked as in the Jurassic sandstone, it is almost always conspicuous enough to attract attention. The whole formation is brilliantly colored. * * * The predominant red, approximating to vermilion, induced Prof. Powell to give the local name of Vermilion Cliffs to their grandest and most typical exposure.

Farther east the distinguishing characteristics of the Vermilion Cliff and the overlying White Cliff sandstone become less conspicuous. Dutton[3] says:

> * * * It has been a long-standing and difficult question whether the Jurassic sandstone is not, after all, a mere upward continuation of the Vermilion Cliff beneath. Much color was given to this supposition by the fact that no unconformity between them has been detected in this vicinity and still more by the fact that as we travel eastward and southeastward from the High Plateaus the distinction between them gradually fades and the two seem to merge into one. Neither of them have yielded any determinable fossils. Nevertheless, I am convinced that the probable plane between the Jura and the Trias lies between these two sandstones. * * *

Gilbert[4] describes the Vermilion Cliff and the "Gray Cliff" (White Cliff) sandstones in the vicinity of the Henry Mountains as follows:

> The Gray Cliff and Vermilion Cliff sandstones are often difficult to distinguish, but the latter is usually the firmer, standing in bold relief in the topography, with level top, and at its edge a precipitous face. The former is apt to weather into a wilderness of domelike pinnacles, so steep sided that they can not often be scaled by the experienced mountaineer, and separated by narrow clefts which are equally impassable.
>
> The colors of the two sandstones are not invariable. The lower, which although not reddened throughout its mass is usually stained upon its surface with a uniform deep color, appears in Mount Ellsworth and at other points of elevation with as pale a tint as that of the Gray Cliff. The latter sandstone, on the other hand, where it lies low, is often as deep in color as the Vermilion. * * * The bleaching of the redder sandstone in Mount Ellsworth is probably a result of metamorphism; the reddening of the gray sandstone may depend on the hydration of the iron which it contains.

This similarity of the two great sandstone formations toward the east has sometimes caused them to be classed as a single formation. Wherever the writer has observed them in eastern Utah, however, he found them to be separated by a weaker shaly member about 100 feet in thickness that usually shows in the topography. The Vermilion Cliff sandstone

[1] Cross, Whitman, The Triassic portion of the Shinarump group of Powell: Jour. Geology, vol. 16, pp. 97-123, 1908. Gregory, H. E., The Shinarump conglomerate: Am. Jour. Sci., 4th ser., vol. 35, pp. 424-438, 1913.

[2] Dutton, C. E., Geology of the High Plateaus of Utah, p. 148, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

[3] Idem, p. 150.

[4] Gilbert, G. K., Geology of the Henry Mountains, p. 7, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1877.

is distinctly the more highly colored, though locally the difference may not be marked.

Powell [1] describes the Vermilion Cliff and White Cliff sandstone in the Uinta region as follows:

In this region the Vermilion Cliff and White Cliff groups are massive sandstones and hence stand in monoclinal ridges. Sometimes the base of the White Cliff group is a series of softer beds, and two ridges are formed. Elsewhere the White Cliff group rises high over the Vermilion Cliff beds in a wall which faces the axis of the Uinta upheaval on either side. Throughout this entire region the White Cliff sandstone is lighter colored than the Vermilion Cliff group and everywhere exhibits that oblique structure known as false bedding.

The age of the Vermilion Cliff sandstone has not been determined by paleontologic evidence, and whether it is really Triassic or Jurassic is open to question. Dutton has, however, classed it with the Triassic and it may well be left there till it is definitely shown to belong elsewhere.

JURASSIC SYSTEM.

The distribution of the Jurassic rocks is much the same as that of the Triassic. They are probably everywhere present in eastern Utah unless removed by erosion. They are most extensively exposed in southeastern Utah, where they outcrop over much of the surface south of latitude 40° 30′ and east of longitude 111° 30′. A broad belt extends through the southern part of the State to the Nevada line, and another encircles the Uinta uplift and borders the Plateau Province on the west. (See Pl. IV.)

The Jurassic, like the Triassic of eastern Utah, can readily be separated into two main divisions, called by Powell the White Cliff group and the Flaming Gorge group. (See Pls. V, VI, in pocket.)

The White Cliff consists almost entirely of a gray cross-bedded sandstone of remarkable similarity over a wide area. Dutton [2] describes this formation for the area of the High Plateau as follows:

The lithological characters of the Jurassic white sandstone render it a very conspicuous formation. Through a thickness of more than 1,000 feet, sometimes of nearly 2,000 feet, it is one solid stratum, without a single heterogeneous layer or shaly parting. * * * The color of the rock is almost always gray, verging toward white. Occasionally it is a very pale cream color, and again pale red. The red becomes more common as we recede from the old shore line towards the east. But of all the features of this rock the most striking is the cross-bedding. It is hard to find a single rock face which is not lined off with rich tracery produced by the action of weathering upon the cross-lamination. * * * The Jurassic sandstone was deposited over an area which can not fall much short of 35,000 square miles, and the average thickness exceeds 1,000 feet.

The formation thins from west to east. Dutton assigns it a thickness of 1,400 feet in the Kanab section, Gilbert 500 feet in the Henry Mountains region, and Lupton 800 feet in the San Rafael Swell region. Farther east, near the La Sal Mountains, Cross [3] assigns a thickness of 550 feet to the La Plata, which he correlates with the White Cliff, and which in western Colorado is reduced to 100 feet. In the Uinta region Powell gives a thickness of 1,025 feet for the White Cliff.

The origin of the White Cliff sandstone and similar formations has been much discussed and is still not generally agreed upon, though the evidence presented in recent years favors a continental origin in which wind was an important factor.[4]

The age of the White Cliff sandstone has not been definitely determined from paleontologic evidence. The formation is overlain, apparently conformably, by marine Jurassic and has been generally considered to be Jurassic. Fossiliferous Jurassic limestones lie a short distance above it over large areas of Utah as far east as Colorado River, beyond which they have not been reported. (For fossil forms characteristic of the Jurassic see Pl. X, p. 79.)

The upper formation of the Jurassic, named Flaming Gorge by Powell, is much more varied in character. Though sections made at many widely separated localities exhibit a general similarity, great differences of detail are shown by sections that are very close together. Dutton says: [5]

That constancy of lithological character which is so conspicuous in older Mesozoic members does not prevail in

[1] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains, p. 151, U. S. Geol. and Geog. Survey Terr., 2d div., 1876.

[2] Dutton, C. E., Report on the geology of the High Plateaus of Utah, p. 152, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

[3] Jour. Geology, vol. 15, pp. 644-645, 1907.

[4] Gregory, H. E., Geology of the Navajo Indian reservation: U. S. Geol. Survey Prof. Paper 93, p. 59, 1917.

[5] Dutton, C. E., op. cit., pp. 153-154.

this one, for it is highly variable not only in the mass, but also in the constitution of the beds. In some exposures it is more than a thousand feet thick; in others, it is less than 200. Where its volume is greatest it is more arenaceous, and where the volume is less the beds are shaly, marly, and calcareous. Usually several seams of limestone occur, and in these the fossils are found, often abundantly. One notable feature is the small amount of cement in the arenaceous layers, which are therefore very poorly consolidated, and the rock weathers and wastes away with extreme facility. Gypsum and selenite occur abundantly in these beds, and especially noticeable is the latter mineral, which is seen sparkling and glittering in the sunlight in the bad lands to which the decay of the strata gives rise.

In the Green River field Lupton[1] separates the formation, which he calls the McElmo, correlating it with the McElmo of Colorado, into three members—the lower "red sandstone," thin bedded above, massive below, thickness about 700 feet; the middle Salt Wash sandstone member (a "gray conglomeratic sandstone which outcrops in cliffs," and is in places "lenticular, soft, and friable"), thickness 150 to 175 feet; and the upper member (a "gray conglomerate, variegated sandy shale, and clay, and a few feet of limestone about 175 feet from the top"), thickness 325 to 350 feet.

The Salt Wash sandstone member in places consists of shale, sandstone, and conglomeratic sandstone, the sandstone usually showing pronounced cross-bedding. In other places, as south of the Henry Mountains and in the vicinity of Bluff, beds that appear to represent the Salt Wash sandstone consist of massive sandstone, of rather uniform texture and strongly cross-bedded, that locally so closely resembles the White Cliff sandstone that it is difficult or impossible to recognize it except by its stratigraphic position. The positions of the beds correlated with the Salt Wash member also show notable differences at different localities. South and east of the La Sal Mountains what is regarded as the Salt Wash sandstone is scarcely more than 200 feet above the White Cliff sandstone, and in the vicinity of Bluff what seems to represent the Salt Wash is separated from the White Cliff by only about 100 feet of red shaly and sandy beds.

The age of the Flaming Gorge formation is somewhat uncertain. The base is unquestionably marine Jurassic, but the assignment of the higher portions of the formation, which were apparently accumulated under subaerial and possibly in part lacustrine conditions, is in doubt, some writers regarding them as Jurassic and others as Cretaceous.[2] On the geologic map (Pl. IV, in pocket), the entire formation is represented as Jurassic.

CORRELATION OF JURASSIC AND TRIASSIC FORMATIONS.

The correlation of the Jurassic and Triassic rocks of Utah with those of Colorado is as yet somewhat uncertain. (See Pls. V, VI, in pocket.)

Cross[3] considers the La Plata sandstone of Colorado as equivalent to the White Cliff sandstone of Utah and the McElmo as the equivalent of the Flaming Gorge.

In following the formations from the Green River region to the Water Pockets flexure and Henry Mountains and thence southeastward to Bluff (see Pl. VI), the writer reached the conclusion that the rocks at Bluff that Woodruff[4] designated upper La Plata are the equivalent of the Salt Wash member of the McElmo of the Green River region, and that the rocks that Woodruff classed as lower La Plata include the White Cliff and Vermilion Cliff formations of the sections farther west. This, however, does not seem to agree with Cross's determination of the upper La Plata south of the La Sal Mountains. Assuming the correctness of Cross's determination of the upper La Plata in the La Sal region, there seems little doubt that the La Plata occupies the stratigraphic position of the White Cliff of Dutton, while the Flaming Gorge is the equivalent of the McElmo.

CRETACEOUS SYSTEM.

Rocks of Cretaceous age, like those of the earlier Mesozoic formations, are largely confined to eastern Utah and extend into the western part of the State near the southern border only. Like the earlier Mesozoic formations they were doubtless deposited over all of eastern Utah but have been removed from large areas by erosion and in other large areas buried beneath later formations. (See Pl. IV.)

In the northern part of the State the Cretaceous is exposed around the Uinta Moun-

[1] Lupton, C. T., Oil and gas near Green River, Utah: U. S. Geol. Survey Bull. 541, p. 124, 1914.

[2] Those interested in a discussion of this subject are referred to Geol. Soc. America Bull., vol. 26, pp. 295-348, 1915.

[3] Cross, Whitman, Jour. Geology, vol. 15, pp. 634-675, 1907.

[4] Woodruff, E. G., Geology of the San Juan oil field, Utah: U. S. Geol. Survey Bull. 471, p. 80, 1912.

tains, its largest outcrop being east of Vernal. It is also exposed in a number of places along the western front of the Plateau province from the Wasatch Range southward by the partial removal of the Tertiary rocks. A broad belt of Cretaceous extends from the Colorado boundary westward, south of the Book Cliffs and in general parallel to the Denver & Rio Grande Railroad, to the vicinity of the San Rafael Swell, thence northwest around the northern end of the swell and southwest nearly to Fremont River. An area of Cretaceous is exposed along the western side of the Henry Mountains, which extends northward nearly to the San Rafael Swell. A large area of Cretaceous is exposed between Escalante and Paria rivers, and from it a belt extends westward as far as Cedar. A narrow belt is exposed around the Pino Mountains. In the southeastern part of the State, north of San Juan River, a large area of Cretaceous extends from the Abajo Mountains eastward into Colorado and there is a small area around the La Sal Mountains.

The Cretaceous sediments are not known to contain metalliferous deposits of commercial importance, and have been studied only incidentally by the writer. They do, however, contain important deposits of coal, which have been carefully studied in many fields and which form the subject of several detailed reports.

The Cretaceous sediments are prevailingly sandstones and shales with some limestones, and were evidently deposited in shallow water. (See Pls. V, VI, in pocket.)

In the Book Cliffs region, Richardson[1] gives the general section of the Cretaceous from the base up as follows:

General section of Cretaceous rocks in the Book Cliffs region.

	Feet.
Dakota sandstone; buff sandstone in many places conglomeratic	20–200
Mancos shale; fissile black to drab clay shales and local lenses of limestone; thin beds of buff sandstone at top mark transition to the overlying formation	3,000
Mesaverde formation; alternating beds of buff sandstone and drab shale; workable beds of coal in lower part	1,200–2,200

Lupton[2] describes a section of over 5,000 feet of Cretaceous beds in the vicinity of the San Rafael Swell, as follows:

Section of Cretaceous beds in vicinity of San Rafael Swell.

	Feet.
Mesaverde formation; mainly sandstone, with intercalated beds of shale and coal	1,100
Mancos shale:	
Shale	3,000±
Sandstone, shale, and coal (Ferron sandstone member[3])	500±
Shale	600+
Dakota sandstone	20–60

For the eastern Uinta Mountains Powell[4] gives a section of 5,000 to 6,000 feet of Cretaceous sediments. For the Henry Mountains region Gilbert[5] gives sections of about 3,000 feet of sandstone and shales that he correlated with the Cretaceous to the north. For southern Utah Richardson[6] describes 3,000 feet of Cretaceous beds. The Cretaceous of the southern Rocky Mountain region has been discussed by Lee, to whose paper those especially interested are referred.[7]

TERTIARY SYSTEM.

Rocks of Tertiary age are exposed over large areas in eastern and central Utah. (See Pl. II.) The largest outcrop is in the Uinta Basin south of the Uinta Mountains, and other large outcrops lie north of the Uinta and east of the Wasatch Range. A broad belt of Tertiary sediments trends southward along the western portion of the Plateau province, locally extending into the Basin Range province, as in the Canyon and adjacent ranges, and finally swinging westward toward the Nevada State line. Over considerable areas in southern Utah the Tertiary sediments are buried beneath volcanic rocks.

The Tertiary rocks contain few metalliferous deposits and, like the Cretaceous, have only incidentally come under the writer's observation. Their chief commercial importance lies in their carbohydrates, especially in the productive gilsonite deposits of the Uinta Basin and the potentially important oil shales.

The Tertiary sediments of Utah were collected in basins or in low areas after the uplift that began at the close of the Mesozoic or early in the Cenozoic. (See Pls. V, VI, in pocket.)

[1] Richardson, G. B., Reconnaissance of the Book Cliffs coal fields: U. S. Geol. Survey Bull. 371, pl. 3, 1909.

[2] Lupton, C. T., Notes on the geology of the San Rafael Swell, Utah: Washington Acad. Sci. Jour., vol. 2, No. 7, p. 188, 1912. Also, Geology and coal resources of Castle Valley, in Carbon, Emery, and Sevier counties, Utah: U. S. Geol. Survey Bull. 628, pp. 33–34, 1916.

[3] Lupton, C. T., Oil and gas near Green River, Grand County, Utah. U. S. Geol. Survey Bull. 541, pp. 124, 128, 129, 1914.

[4] Powell, J. W., Report on the geology of the eastern portion of the Uinta Mountains, p. 49, U. S. Geol. and Geog. Survey Terr., 2d div., 1876.

[5] Gilbert, G. K., Report on the geology of the Henry Mountains, p. 4, U. S. Geog. Surveys Rocky Mtn. Region, 1877.

[6] Richardson, G. B., The Harmony, Colob, and Kanab coal fields, southern Utah: U. S. Geol. Survey Bull. 341, p. 379, 1909.

[7] Lee, W. T., Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 95, pp. 27–58, 1915.

The character of the sediments in the Uinta Basin is given by Eldridge[1] as follows:

Formations of the Uinta Basin.

Series.	Formation name.	Maximum thickness, in feet.[a]	Description.
Eocene.	Uinta.	500-1,000	Conglomerate, sandstone, and shale, the first two predominating, especially toward the top. Material derived chiefly from Paleozoic quartzites of Uinta Range and Yampa Plateau. Prevailingly red to pink, though many of the sandstones are rusty yellow to brown.[b]
	Washakie.	200	Sandstone and shale. Difficultly recognizable.[c]
	Bridger.	600-1,000	Conglomerate, sandstone, shale, and some 1 to 2 foot layers of white limestone. Sandstones prevail; they are heavy bedded, somewhat ferruginous, and gray to rusty yellow and chocolate-brown. Conglomerate fine. Formation said to be identified by vertebrate remains.
	Green River.	2,000	Calcareous shales and thin limestones. Shales and limestones bituminous, locally, in a degree to be of economic value. Prevailing color gray, weathering light. Some thin sandstone layers, becoming more prominent toward top. Country deeply eroded.
	Wasatch.	1,000-1,500	Conglomerates and sandstones in heavy beds; red.

[a] Largely estimated.

[b] According to J. B. Hatcher the Uinta of this region is the equivalent of Osborn's *Diplacodon elatus* beds.

[c] Equivalent to the top of the Bridger, according to some authorities. [The United States Geological Survey now includes these beds in the Bridger.]

[1] Eldridge, G. H., The uintaite (gilsonite) deposits of Utah: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 1, p. 922, 1896.

The general character of the Tertiary beds in the vicinity of the High Plateau is described by Dutton[2] as follows:

The Tertiary system of the Plateau Country is lacustrine throughout, with the exception of a few layers near the base of the series, which have yielded estuarine fossils. The widely varying strata were accumulated upon the bottom of a lake of vast dimensions, and were derived from the waste of mainlands and mountain platforms, some of which are still discernible. The region of maximum deposit was in the vicinity of the Wasatch and Uintas, where in the course of Eocene time more than 8,000 feet of beds were laid down. As we proceed southward, these heavy deposits attenuate, partly by a diminution in the thickness of the individual members and partly because the period of deposition ceased earlier the farther southward we go, until in the southern part of the province only the lower Eocene is found, or, indeed, was ever deposited. The High Plateaus occupy the belt through which this diminishing bulk and successive elimination of upper members is well seen. In the Wasatch Plateau, at the extreme northern part of the district, we find the two lower divisions of the Eocene present in great volume; and in the valley of the Sevier and San Pete we find what is undoubtedly a still higher division. At the southern portion of the district only the lower division can be clearly made out, though some of the upper beds may prove to belong to a later period. The present weight of evidence, however, seems to me to place them in one division, the "Bitter Creek"[3] of Powell.

In the southern plateaus, the Markagunt and Paunsagunt, we find the following members of the Bitter Creek, which are much the same in all exposures:

Southern Bitter Creek.

	Feet.
1. Upper white limestone and calcareous marl (summit of series)	300
2. Pink calcareous sandstone	300
3. Pink conglomerate (base of the series)	550
	1,650

In the northern part of the district we have a larger development of the Bitter Creek series, and resting upon it some heavy masses of the Lower Green River shales, and probably a considerable portion of the Upper Green River Group.

The Pink Cliffs, which form such a striking feature in the scenery of the southern terraces, are exposures of the fine-grained calcareous sandstone forming the middle member of the Bitter Creek. The same exposures are exhibited in the southern and southwestern flanks of the Markagunt around the entire promontory of the Paunsagunt and in the circuit of the Table Cliff. In the Aquarius Plateau the Lower Eocene is found, but in smaller volume than elsewhere, and it is decidedly diminished in mass upon the summit of Thousand Lake Mountain. But it resumes its normal thickness farther north, and then grows more and more massive throughout the extent of the Wasatch Plateau.

[2] Dutton, C. E., Geology of the High Plateaus of Utah, pp. 158-159, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

[3] The name Bitter Creek group is no longer in use. In its typical area the group included all the rocks between the top of the Lewis shale and the top of the Bridger formation.

In their general characteristics these Tertiary strata are similar to the Laramie beds upon which they generally rest, being shaly and marly and sometimes lignitic.

In northwestern Utah tuffaceous beds around the northern end of the Pilot Range and in the Grouse Creek valley are supposed to be of Tertiary age, and more detailed study may reveal other Tertiary sediments in western Utah.

Those especially interested in a discussion of the Tertiary stratigraphy are referred to W. D. Mathews's paper[1] on the subject.

QUATERNARY SYSTEM.

The Quaternary deposits of the State may be roughly separated into three principal types—glacial deposits, lake deposits, and valley deposits.

GLACIAL DEPOSITS.

Glacial deposits are confined principally to high altitudes and their surrounding areas. The largest deposits are present around the Uinta Range. Others are present around the higher portions of the Wasatch Range, notably in the vicinity of the Cottonwood and American Fork canyons. The deposits in both these ranges have been mapped and described by Atwood,[2] by whom deposits of two periods are definitely recognized.

In other parts of the State small areas have been glaciated. The higher portions of the Tushar Range[3] and, according to Dutton, the higher portions of the High Plateau[4] contained glaciers, and Hill reports glacial deposits in the La Sal Mountains.[5]

It is probable that such deposits occur in the Abajo (Blue) Mountains, but they have not been recognized in the Henry Mountains. Woodruff[6] and Sterrett[7] have described a deposit of till-like material in San Juan County, near the Arizona boundary, which was regarded of possible glacial origin. Gregory,[8] however, has shown that it is probably an intrusive breccia.

On the geologic map (Pl. IV) no attempt has been made to show the glacial deposits, as they are of relatively slight importance.

LAKE DEPOSITS.

While glaciers were accumulating on the higher elevations water collected in the lower areas, and a lake, from which the tops of the Basin Ranges projected as islands, spread over a large area in western Utah. This lake, which may be regarded as a vast expansion of the present Great Salt Lake, has been called Lake Bonneville. The streams flowing from the mountains brought to it large amounts of sediment, which were distributed by the waves. Terraces represent the beach and near-shore deposits of the lake, and rock-cut benches on the exposed headlands exhibit the work of the waves.

Two shore lines, distinct in many localities, mark levels at which the waters of the lake were stationary for considerable periods, and other less distinct lines mark levels at which the waters were comparatively stationary for shorter periods. The extent of the lake and its shore features have been fully described and discussed by Gilbert.[9] While the shore features were being formed deposits were of course being laid down in the deeper portions of the basin, but these have for the most part been buried beneath later deposits and are largely inaccessible to observation.

The deposits of the Great Salt Lake desert are doubtless, in general, similar to those forming in the present lake. They consist of saline muds and locally of beds of salt of considerable extent that accumulated in places where the desert was flooded only at intervals. In Great Salt Lake there have formed and still are forming deposits consisting very largely of oolitic grains composed of calcium carbonate. On the geologic map (Pl. IV) no attempt has been made to separate the lake deposits from the other Quaternary deposits.

VALLEY DEPOSITS.

In the low areas, especially in the valleys between the desert ranges, large quantities of rock material from the higher elevations have accumulated. Many of the streams are intermittent, flowing on the surface only during

[1] The Tertiary sedimentary record and its problems: Problems of American geology, Yale University Press, 1915.

[2] Atwood, W. W., Glaciation of the Uinta and Wasatch mountains: U. S. Geol. Survey Prof. Paper 61, 1909.

[3] Lindgren, Waldemar, The Annie Laurie mine, Piute County, Utah: U. S. Geol. Survey Bull. 285, p. 89, 1906.

[4] Dutton, C. E., The Tertiary history of the Grand Canyon district: U. S. Geol. Survey Mon. 2, p. 202, 1882.

[5] Hill, J. M., Notes on the northern La Sal Mountains, Utah: U. S. Geol. Survey Bull. 530, p. 105, 1913.

[6] Woodruff, E. G., Geology of the San Juan oil field, Utah: U. S. Geol. Survey Bull. 471, p. 89, 1912.

[7] Sterrett, D. B., U. S. Geol. Survey Mineral Resources, 1908, pp. 823-827, 1909.

[8] Gregory, H. E., The igneous origin of the "glacial deposits" on the Navajo Reservation, Arizona and Utah: Am. Jour. Sci., 4th ser., vol. 40, pp. 97-115, 1915.

[9] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, 1890.

torrential rains and even then sinking into the soil close to the points where they emerge from the ranges. The relatively few streams that maintain a perennial flow likewise sink into the soil in whole or in part after they reach the relatively flat desert valleys. Conditions are therefore favorable for transporting large amounts of rock material to the mouths of the mountain canyons and dropping them to build up the immense débris fans or cones that characterize the desert regions. These fans spread out laterally from the mouths of the valleys and in places coalesce into a continuous débris apron. Outwardly from the mountain front they decrease in slope and become progressively finer grained till they finally flatten out and can be no longer recognized. In many desert valleys, however, débris fans from ranges on opposite sides reach the center and coalesce; and everywhere the fine material is gradually carried to the lower areas, so that the surface is being gradually built up.

Little is known concerning the thickness of the valley deposits, and in areas that were covered by the Quaternary lakes it is not always easy to separate deposits formed in the lake from those deposited in the dry valleys both before and after the lake period. Wells have penetrated these deposits for several hundred feet, and there can be little doubt that in some places they are thousands of feet in thickness. So far as ascertained, they consist of a very variable succession of clay, sand, and gravel.

Stream deposits are a form of valley deposits. They are comparatively insignificant in amount but are economically important, for they are the only recent deposits that have yielded metals. Important amounts of gold have been obtained from them in Bingham Canyon, less amounts from Green, Colorado, and San Juan rivers, and very small amounts from some other localities.

IGNEOUS ROCKS.

GENERAL DISTRIBUTION.

Igneous rocks are widely distributed in Utah and over large areas are the prevailing surface formation. They are closely associated with many of the metalliferous deposits of the State and are consequently of great interest to those engaged in metal mining. The igneous rocks may be separated into extrusive rocks, or those that have flowed out on the surface and solidified, and intrusive rocks, or those that have solidified beneath the surface.

The great bulk of the igneous rocks is confined to two zones, each of which contains both intrusive and extrusive rocks. The largest of these zones lies in the southern part of the State, where it extends from the High Plateau through the Basin Range province to eastern Nevada (Pl. IV, in pocket). Farther east it may be regarded as represented by the detached laccolithic masses of the Henry, Abajo, and La Sal mountains. This great belt can be subdivided, as will be indicated later.

The second zone extends from the western end of the Uinta Mountains westward and southwestward across the State, including the igneous masses in the Wasatch, Oquirrh, Tintic, Sheeprock, Dugway, Granite, Deep Creek, and other ranges. It may be subdivided into a northern division extending from the Uinta Mountains westward to Bingham, and a southern division extending from the latitude of Mount Nebo westward through the Tintic, Dugway, Deep Creek, and other ranges.

Smaller areas of igneous rocks outcrop in the Raft River Mountains in the northwestern part of the State, in the Pilot Range near the Nevada State line, and in many other localities.

The extrusive rocks (see Pl. IV) cover a much larger area than the intrusive, especially in the southern belt, where great areas have been buried by lavas in some localities to a depth of hundreds of feet. It is not improbable that lavas were once much more extensive in the northern belt and have been largely removed by erosion. Such erosion may not only have actually decreased the amount of extrusive rock but, by revealing the intrusive bodies, may also have increased the apparent relative proportion of the intrusive rocks in the northern area.

EXTRUSIVE ROCKS.

CHARACTER AND ORIGIN.

The extrusive rocks include some lava, but they are in greater part fragmental. In the southern part of the State, especially, large bodies consist of clastic or fragmental material. According to Dutton, the great bulk of this material in the High Plateau region

	Great Basin, Spurr.		High Plateau, Dutton.
5	Olivine basalt.	Ultra-acid rhyolite or tordrillite.	
	Augite basalt.	Biotite rhyolite.	Basalt.
	Hornblende basalt.	Biotite-hornblende rhyolite.	
4	Pyroxene-olivine aleutite.	Hornblende-biotite latite.	Dolerite.
	Pyroxene aleutite.	Biotite-hornblende dacite.	Augite andesite.
	Hypersthene-hornblende aleutite.	Biotite-augite-hornblende-quartz latite.	Sana
	Hornblende-pyroxene-biotite aleutite.	Augite-biotite-hornblende latite.	Hornblende andesite.
	Pyroxene andesite.	Hornblende pyroxene andesite.	Hornblen
	Pyroxene-hornblende andesite.		Hornblende propylite.
3.	Biotite rhyolite.	Olivine basalt.	
2	Latite (?)		
	Dacite.		
	Hornblende-quartz andesite.	Pyroxene andesite (?)	
	Biotite andesite.		
	Hornblende andesite.		
	Hornblende-pyroxene andesite.		
	Pyroxene-hornblende andesite.		
1	Biotite rhyolite and tordrillite.		

Comparison of some sections of volcanic rocks in Utah with generalized sections proposed by Dutton and Spurr.

lateau, Dutton.	Iron Springs, Leith and Harder.	Meadow Valley Canyon, Nev., Spurr.	East Tintic Range,
	9. Biotite-hornblende-pyroxene andesite.		Olivine basalt.
Rhyolite.	8. Late tuffaceous rhyolite.	Rhyolite-tordrillite. Pyroxene-olivine basalt. Rhyolite.	
Liparite.			
Sanadine trachyte.	7. Biotite dacite.	Biotite-hornblende rhyolite.	Augite-hypersthene latite. Hornblende-augite-biotite Hornblende-augite latite.[1]
ndesite.	6. Pyroxene andesite.	Biotite-hornblende dacite.	Biotite-augite-hypersthene lat Biotite-augite latite.
Hornblende trachyte.	5. Latest trachyte.	Biotite-hornblende-quartz latite.	Augite latite. Latite tuff.
lende propylite.	4. Hornblende andesite.	Pyroxene andesite.	
	3. Later trachyte. 2. Early tuffaceous rhyolite. 1. Early trachyte.		Biotite rhyolite. Rhyolite tuff. Biotite rhyolite.
			Biotite-augite andesite or latit
		Biotite rhyolite.	

[1] Exact relation to other latites uncertain.

East Tintic Range, Loughlin.	San Francisco Range, Butler.	Park City, Boutwell and Woolsey.	Gold Springs, Utah.
basalt.	Basalt.		
			Rhyolite.
ypersthene latite. nblende-augite-biotite latite.[1] nblende-augite latite.[1]	Dacite, latite, and andesite, with some rhyolite.	Andesite flows and tuffs.	Latite.
ugite-hypersthene latite or andesite. ugite latite.			
atite. ff.			
yolite. tuff. yolite.	Rhyolite tuff.		
gite andesite or latite.	Dacite and andesite.		
			Rhyolite tuff.

is not true tuff resulting from explosive volcanism but is the result mainly of the breaking down of earlier lavas and the deposition of the resulting material as volcanic sediments. The same is probably true of large bodies of fragmental material in the southwestern part of the State and in adjacent parts of Nevada.[1] The most extensive fragmental beds are near the base of the extrusive series. Higher in the series at several localities is some fragmental material that is probably true tuff.

The nature of the eruptions which resulted in the great accumulation of extrusive material is not everywhere clear, and much more work will be required before it can be definitely outlined for the entire series. That the later eruptions were what are commonly termed central rather than fissure eruptions, though the centers may be closely associated with fissures, is indicated by numerous cones that are scattered over the southern Utah field. In the case of the older deposits where erosion has largely or entirely removed the ancient volcanic cones, the arrangement and attitude of the flows frequently indicate that they originated from centers. Several centers from which the great body of extrusive rocks of the High Plateau region emanated have been identified by Dutton; and to the north in the Tintic Mountains three centers of eruption have been located. (See p. 398.) However, some at least of the southern flows, especially the earlier ones, were not improbably allied to fissure eruptions, though they may have been confined to numerous centers along the fissures.

In composition the rocks range from rhyolite to basalt, but the great bulk of the series is of intermediate composition, including rather basic rhyolites, quartz latites, dacites, and andesites. Basalt is very subordinate in amount when compared with the series as a whole, though present in many localities and usually conspicuous as representing the latest volcanic outflows. The alkaline types of rock, such as the leucite and nepheline-bearing lavas, are very scarce, having been noted only in East Fork Canyon, where Dutton[2] has described an isolated occurrence of phonolite. It is not improbable that detailed work will disclose other areas of alkaline lava, but it seems certain that they are rare and are nowhere of large extent.

[1] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel: U. S. Geol. Survey Bull. 208, p. 140, 1903.

ORDER OF ERUPTION.

The relation of the different types of volcanic rocks to one another and the relative time of their expulsion is a matter of much interest, but sufficient data are not available to warrant definite generalizations.

From his studies in the High Plateau region Dutton[3] suggested a generalized order of eruption, based partly on the earlier order suggested by Richthofen, that seemed to agree with the observed order at different localities in that area. Later Spurr[4] proposed a more complicated system to which he referred the lavas over a wide area in the Great Basin region.

The accompanying table compares several sections of the Utah volcanic rocks with the generalized sections of Dutton and Spurr.

Though most of the observed sections can be made to fit into the generalized sections so far as regards general chemical composition, it is apparent that they show much greater variation in mineral composition. Ransome[5] has suggested that the apparent agreement with the generalized series of Spurr in the Goldfield district, Nevada, is due to the fact that almost any limited series can be made to fit the system, and the writer inclines to the same view for the Utah districts. So far as he has been able to determine in his study of the effusive rocks in Utah the succession of different lavas is not sufficiently regular to permit confident predictions as to the kind of lava that underlies any particular kind that is exposed on the surface. Comparison of the different sections, however, does show that in Utah the great bulk of the lavas is of intermediate composition and that the latest eruptions are basaltic.

[2] Dutton, C. E., Geology of the High Plateaus of Utah, p. 248, U. S. Geog. Survey Rocky Mtn. Region, 1880.

[3] Idem, p. 68.

[4] Spurr, J. E., Lavas in the Great Basin region: Jour. Geology, vol. 8, p. 643, 1900.

[5] Ransome, F. L., Geology and ore deposits of Goldfield, Nev.: U. S. Geol. Survey Prof. Paper 66, p. 106, 1909.

CHEMICAL COMPOSITION.

In the following tables the published chemical analyses of the effusive rocks of the State are brought together for comparison:

Analyses of extrusive rocks from Iron Springs district.[a]

Chemical composition.

	1	2	3	3a	4	5
SiO_2	64.83	58.04	66.38	70.03	73.17	61.05
Al_2O_3	16.68	18.96	13.72	14.47	13.34	16.03
Fe_2O_3	3.74	5.88	2.23	2.35	1.35	5.42
FeO	1.22	1.33	.80	.84	.76	.98
MgO	.79	1.11	.54	.57	.81	3.03
CaO	2.85	6.12	5.49	2.42	1.32	5.40
Na_2O	.86	2.26	2.50	2.64	1.80	1.43
K_2O	7.56	4.08	5.20	5.48	7.10	5.58
H_2O	.92	2.05	.92	.97	.54	.81
P_2O_5	.35	.34	.08	.08	.07	.30
CO_2	......	......	2.52	......	......	......
BaO	.11	.04	.11	.11	.10	.08
	99.91	100.21	100.49	99.96	100.36	100.11

[a] Leith, C. K., and Harder, E. C., The iron ores of the Iron Springs district, southern Utah: U. S. Geol. Survey Bull. 338, p. 58, 1908.

Mineral composition calculated from chemical composition.

	1	2	3	4	5
Quartz	22.02	15.06	27.60	33.12	19.38
Orthoclase	43.37	22.79	28.35	39.47	28.35
Albite	7.34	18.86	20.96	15.19	12.05
Anorthite	11.12	25.85	10.56	5.56	15.84
Biotite[a]	3.81	3.71	3.70	2.70	2.70
Phlogopite[a]	......	......	......	1.62	4.16
Diopside	.86	2.16	......	......	7.12
Magnetite	1.85	2.78	1.62	.92	1.85
Apatite	.62	.62	.31	.31	.62
Limonite	.75	4.11	.56	.75	.75
Hematite	1.28	......	......	......	3.52
Calcite	......	......	5.70	......	......
Kaolin	5.10	3.09	......	......	3.61
Water	......	.97	.76	.34	......
Sillimanite	1.45	......	......	......	......
	99.63	100.00	100.12	99.98	99.95

[a] Composition based on average of analyses in Dana's Manual of mineralogy.

1. Specimen 46533. Fresh early trachyte from Antelope Range (No. 1 of flows). Analysis by R. D. Hall, University of Wisconsin.

2. Specimen 46584. Andesite from same formation as specimen C north of Stoddard Mountain. Analysis by R. D. Hall, University of Wisconsin.

3. Specimen 46521. Early rhyolite from Eightmile Hills (No. 2 of flows). Analysis by R. D. Hall, University of Wisconsin.

3a. Specimen 46521. Early rhyolite. Recalculated on the basis of 100 per cent after removing CaO and CO_2 of the infiltrated calcite.

4. Specimen 46557. Latest trachyte from Antelope Hills (No. 5 of flows). Analysis by R. D. Hall, University of Wisconsin.

5. Specimen 46586A. Dacite from Swett Hills (No. 7 of flows). Analysis by R. D. Hall, University of Wisconsin.

Chemical analyses of lavas from the San Francisco and adjacent districts.

Chemical composition.

	1	2	3	4	5
SiO_2	68.04	67.93	64.48	63.04	57.72
Fe_2O_3 / FeO	19.02	19.46	......	21.98	......
MgO	.84	.28	None.	1.49	.90
CaO	2.76	1.42	1.95	4.13	6.40
Na_2O	4.66	3.54	4.81	3.43	4.94
K_2O	4.27	3.91	3.39	3.26	4.36

Probable mineral composition of crystalline rock.

	1	2	3	4	5
Quartz	21	31	20	21	......
Orthoclase molecule	25	22	20	18	26
Albite molecule	34 } 44	30 } 37	40 } 50	28 } 44	42 } 62
Anorthite molecule	10	7	10	16	20
Hornblende, augite, and biotite	7	3	......	9	6

1. Heavy-bedded lava southeast of Squaw Springs (specimen 49).
2. Thin-bedded lava northeast of Frisco (specimen 20).
3. Lava from prospect 1¼ miles north of O. K. mine (specimen 187).
4. Lava northeast of Carbonate mine (specimen 22).
5. Lava from northwestern part of Star district (specimen 148).

Chemical analyses of effusive rocks from Tintic, Park City, and Marysvale districts and from Thomas Range.

Chemical composition.

	1	2	4	5
SiO_2	74.49	70.17	69.18	60.17
Al_2O_3	14.51	11.83	14.37	15.78
Fe_2O_3	.57	.93	2.52	3.42
FeO	.32	......	.57	2.95
MgO	Trace.	.06	.70	2.52
CaO	1.03	.76	1.88	4.69
Na_2O	3.79	3.85	3.58	2.96
K_2O	4.64	3.74	5.00	4.16
H_2O	.64	8.72	......	......
H_2O-	......	......	.35	.25
H_2O+	......	......	.25	1.23
P_2O_5	......	......	.26	.40
CO_2	......	......	......	......
BaO	......	......	.09	.14
TiO_2	......	.17	.69	.87
MnO	Trace.	......	.10	.11
Li_2O	Trace.	......	Trace.	Trace.
ZrO_2	......	......	......	......
Cl	......	......	Trace.	.04
FeS_2	......	......	......	......
SrO	......	......	Trace.	[illegible]
Cr_2O_3	......	......	Trace.	......
V as V_2O_5	......	......	.01	[illegible]
Mo	......	......	Trace.	......

Chemical analysis of effusive rocks from Tintic, Park City, and Marysvale districts and from Thomas Range—Con.

Norm or theoretic mineral composition.[a]

	1	2	4	5
Quartz	32.4	31.8	24.0	13.6
Orthoclase	27.8	22.2	30.0	25.0
Albite	32.0	32.5	30.4	25.2
Anorthite	5.0	3.6	8.1	17.0
Hypersthene	......	.2	1.3	5.0
Hematite	......	.9	2.5	......
Diopside	......	......	1.1	5.3
Ilmenite	......	......	1.2	1.7
Magnetite	.9	......	......	4.9
Corundum	1.3	......	......	......

[a] Washington, H. S., Chemical analyses of igneous rocks: U. S. Geol. Survey Prof. Paper 99, pp. 125, 183, 1917.

1. Rhyolite, Thomas Range. Analysis made by L. G. Eakins in the Denver Laboratory.
2. Rhyolitic glass or pitchstone, edge of Gold Mountain mining district, 8 miles north of west from Marysvale. Analysis by W. F. Hillebrand, record No. 1833.
4. Packard rhyolite, Tintic district. Analysis by Dr. Stokes.
5. "Tintic" andesite, or latite. Analysis by Dr. Stokes.

INTRUSIVE ROCKS.

DISTRIBUTION AND CHARACTER.

Intrusive rocks are widely distributed over the western part of the State and are present at several localities in the southeastern part.

In the western part the principal large bodies from north to south are in the Raft River Range in the northwestern corner of the State; the Pilot Range on the Nevada border; the east-west belt extending from the Park City region westward through the Little Cottonwood and the Bingham regions; the belt extending from the Tintic Range westward in the Sheeprock, Granite, and Deep Creek ranges; the igneous belt extending from the San Francisco Range eastward through the Beaver Lake, Rocky, Star, Mineral, and Tushar ranges to the Antelope district northeast of Marysvale; and the belt which extends southwestward through the Iron Springs district and the Bull Valley region and is reported to continue into Nevada. In the southeastern part of the State are the laccolithic bodies of the Henry, Abajo, and La Sal mountains. Small intrusive bodies like dikes and sills are present at numerous other localities in the State.

Intrusive bodies have been given names depending on their shape, size, relation to surrounding rocks, and supposed mode of origin. For the purpose of the present discussion it will be sufficient to state what is meant by a few of the terms when used in this report. (See fig. 6, p. 92.)

A dike is an injected body, has nearly parallel walls, is narrow in proportion to its outcropping edge, cuts across the bedding when the injected formation is stratified, and has any angle of dip.

A sheet or sill is a tabular injected body lying parallel to the bedding planes of the country rock.

A laccolith is closely related to a sheet or sill but typically has a more lenticular form, the overlying rocks or roof being raised as a dome over the thicker portion, or the underlying rocks or floor perhaps depressed into a basin. The distinguishing and important feature of the laccolith is that it has a floor separating it from lower bodies of similar material and that the opening through which its material entered is relatively small.

A stock extends indefinitely downward and in many instances increases in area with increasing depth. It has no floor and consequently is not separated from the source of its material. A stock of large dimensions is frequently termed a batholith.

The laccoliths and stocks of the State are rather definitely separated geographically, the intrusive bodies of the southeastern part of the State being typically laccoliths and those of the western part typically stocks. There may be some true laccoliths in the western area but there are probably no true stocks in the southeastern.

MODE OF INTRUSION.

The space occupied by an intrusive body may be considered as having been formed in either one of two ways or by a combination of the two. It may have been formed by the pushing upward or aside bodily of the material previously occupying the space, or it may have been formed by the assimilation of that material in the intruding body. Assimilation may take place in several ways. The molten material may have simply dissolved the rock and thus advanced into the solid rock mass, or it may have wedged off blocks from the top or sides or even from the bottom of the chamber. If these blocks are heavier than the

molten material, they will sink until dissolved. If they are lighter, they will rise. By this method, which is called by Daly magmatic stoping, a body of molten rock could advance into a solid formation without disturbing the position of the invaded rocks other than those immediately affected.

the associated rocks that is well developed in the Central Wasatch, in the Raft River Range, and less clearly in many other places. The stocks, however, are distinctly crosscutting bodies, and the doming can not account for all the rock displaced. In some localities these crosscutting bodies have formed the space, in

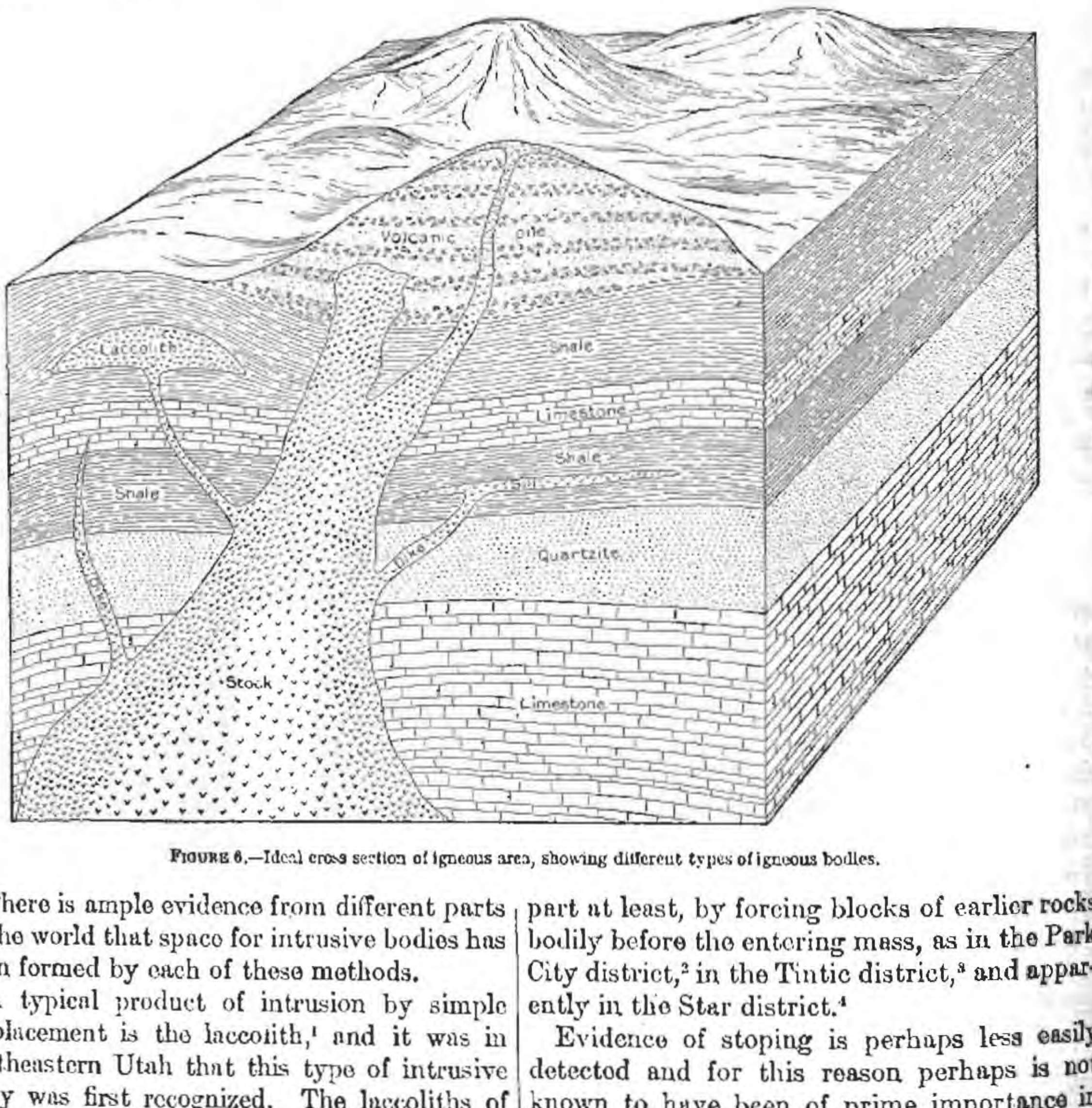


FIGURE 6.—Ideal cross section of igneous area, showing different types of igneous bodies.

There is ample evidence from different parts of the world that space for intrusive bodies has been formed by each of these methods.

A typical product of intrusion by simple displacement is the laccolith,[1] and it was in southeastern Utah that this type of intrusive body was first recognized. The laccoliths of this region clearly were formed by the doming up of the sedimentary strata, to which the intrusive contacts are for the most part parallel. There is no evidence of material assimilation of the sedimentary rocks by the intruded magma.

The stocks in the western part of the State also show evidence of displacement of the earlier rocks, especially in the dome structure of

part at least, by forcing blocks of earlier rocks bodily before the entering mass, as in the Park City district,[2] in the Tintic district,[3] and apparently in the Star district.[4]

Evidence of stoping is perhaps less easily detected and for this reason perhaps is not known to have been of prime importance in Utah. In the Tintic district there is abundant evidence of stoping, but all of it is later than the faulting due to the igneous intrusions.

Numerous blocks of sediment are included in the stocks of the San Francisco Range, the Raft River Range, the Park City district, and the

[1] Gilbert, G. K., Report on the geology of the Henry Mountains, 160 pp., U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1877.

[2] Boutwell, J. M., and Woolsey, L. H., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, p. 97, 1912.

[3] Lindgren, Waldemar, and Loughlin, G. F., Geology and ore deposits of the Tintic mining district, Utah: U. S. Geol. Survey Prof. Paper 107, 282 pp., 1919.

[4] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, p. 71, 1913.

Tintic district. In the Park City district[1] bodies of Pennsylvanian and Mississippian limestone have been raised many feet above their normal position, and the same is true of a body of quartzite in the Tintic district; but in neither locality has it been shown that there has been important assimilation of the included blocks.

Leith and Harder consider that there has been a notable shrinkage of the limestone adjacent to the intrusives in the Iron Springs district. This, however, could provide only a small fraction of the space occupied by the intrusive bodies.

The available evidence indicates that most of the space occupied by the visible parts of the

FIGURE 7.—Ideal cross section of grouped laccoliths. After Gilbert.

intrusive bodies was formed by a displacement of the earlier rocks and little of it by assimilation.

LACCOLITHS.

Laccolithic bodies have been exposed by erosion in the Henry, Abajo, and La Sal mountains. In other areas, for example, in Navajo Mountain and the San Rafael Swell, the structure suggests the presence of similar bodies that have not yet been revealed by erosion.

The three groups are of a single type. Each is composed of numerous laccoliths, sheets, and dikes intruded into the sedimentary rocks from the Triassic to the Cretaceous. They range from bodies only a few feet thick, whose lateral dimensions are measured in rods, to bodies hundreds of feet thick which cover several square miles. In form they show every gradation from the true sheet with essentially parallel floor and roof to lenticular laccoliths with high-domed roofs. (See fig. 7.)

Rocks from different bodies differ greatly in general appearance, principally owing to the different conditions under which they were solidified. All are porphyritic, but in some the groundmass is very fine and the rocks resemble surface flows, for which indeed they have sometimes been mistaken where erosion has removed the overlying sediments. In the larger bodies much of the groundmass is rather coarsely crystalline and even granitic in texture.

As a group the rocks are characteristically of intermediate composition, not only in Utah but also in Colorado and Arizona.[2] The difference in the composition of different bodies would be considered great enough to justify different petrographic names were it not that equally great differences occur in single rock masses. All the rocks have the general composition of quartz monzonites or granodiorites.

The following tables contain chemical analyses of rocks from the La Sal and the Henry mountains:

Analyses of rocks from the La Sal Mountains.

	1	2	3	4	5	6
SiO_2	61.21	73.27	70.02	68.96	62.64	58.99
Al_2O_3	17.10	13.29	14.38	15.42	17.36	19.01
Fe_2O_3	2.72	1.16	1.17	1.99	2.79	1.74
FeO	1.88	.13	.13	.16	.63	.59
MgO	1.47	.07	.61	.22	.53	.27
CaO	4.83	.21	.66	.25	1.70	2.02
Na_2O	5.66	3.44	5.48	6.59	7.00	9.11
K_2O	3.00	7.53	5.87	5.48	4.97	5.07
H_2O-	.34	.23	.27	.22	.43	.38
H_2O+	.68	.43	.44	.30	.53	1.24
TiO_2	.51	.10	.10	.12	.43	.21
ZrO_2	.02	.02	.01	.04	.02	.07
CO_2	None.	.02	.38	.13	.54	None.
P_2O_5	.24	Trace.	Trace.	Trace.	.12	.04
SO_3	None.	.07	.19	None.	.06	.96
Cl	.04	.01	.03	.01	.03	.15
MnO	.15	.03	.02	.07	.04	.08
BaO	.13	.10	.13	Trace.	.10	.02
SrO	.07	None?	.06	None.	.07	.02
Li_2O	Trace?	Trace?	Trace.	Trace.	None.	Trace.
	100.05	100.11	99.95	99.96	99.99	99.97

1. Monzonite porphyry, 2 miles west of Mount Peale. Analysis by W. F. Hillebrand.
2. Aegirite granite porphyry, about 1.5 miles south of Mount Waas. Analysis by W. F. Hillebrand.
3. Syenite aplite porphyry resembling grorudite. About 2 miles south of Mount Waas. Analysis by W. F. Hillebrand.
4. Syenite porphyry resembling sölvsbergite. About 1 mile northwest of Mount Waas. Analysis by W. F. Hillebrand.
5. Pulaskite, 1 mile west of Mount Waas. Analysis by W. F. Hillebrand.
6. Noselite syenite porphyry, dike on northwest shoulder of Mount Waas. Analysis by W. F. Hillebrand.

[1] Boutwell, J. M., and Woolsey, L. H., p. 97, 1912.

[2] Cross, Whitman, The laccolithic mountain groups of Colorado, Utah, and Arizona: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, p. 227, 1893.

Chemical analyses of rocks from Henry Mountains.

Chemical composition.

	1	2	3
SiO_2	63.16	62.88	60.98
Al_2O_3	17.21	17.13	19.09
Fe_2O_3	2.43	1.86	1.76
FeO	2.30	2.58	1.15
MgO	1.27	1.48	.65
CaO	6.27	5.39	3.67
Na_2O	4.70	4.50	6.70
K_2O	1.84	2.25	3.53
H_2O-	....	.16	.48
H_2O+	.69	.42	.44
TiO_2	.21	.51	.36
CO_2	....	....	.52
P_2O_5	.12	.26	.10
SO_3	Trace.	....	....
MnO	Trace.	.16	.15
BaO	.09	.16	.43
SrO	Trace?	.12	.28
Li_2O	Trace.	Trace.	Trace.
	100.29	100.29	99.86

Approximate mineral composition.

	1	2	3
Quartz	14.8	11.9	1.3
Orthoclase molecule	11.1	13.3	20.6
Albite molecule	39.8	37 7	56.6
Anorthite molecule	20.3	20.0	11.7
Hornblende and augite	9.6	8.9	4.8
Magnetite	3.5	2.8	2.6
Ilmenite	.5	.9	.8

1. Porphyry. Analysis by W. F. Hillebrand.
2. Hornblende porphyrite. Sheet, revet-crag, Mount Hellers. Analysis by W. F. Hillebrand.
3. Augite porphyrite. Dike on north spur of Mount Pennell. Analysis by W. F. Hillebrand.

In the smaller laccolithic bodies no later dikes are present, and in the larger laccoliths they are few and small. Such rocks have been carefully studied in the La Sal Mountains by Prindle, who finds them high in alkalies, especially sodium, and low in calcium and magnesium. Detailed study of the other groups will doubtless reveal dikes associated with the larger laccoliths; some, indeed, are known to be present in the Henry Mountains.

The similarity in the composition of the several laccolithic bodies in a group and the absence of dikes from all but the larger are characteristic. These conditions may be explained as follows: The material forming the laccolith entered the space it occupies through a relatively narrow opening, which, it is reasonable to suppose, was quickly choked once the active flow of material ceased, and the laccolithic body was thereby effectually sealed off from the deep-seated sources. In small and relatively thin bodies the molten material solidified quickly and the part remaining longest fluid had little opportunity to form dikes of a composition differing from that of the main body of the laccolith. In the larger laccoliths, however, the inner portions may have solidified slowly and have remained partly fluid after the outer crust was sufficiently solid to permit fissuring. This fluid portion might readily have been squeezed into the fissures in the solid crust and, solidifying there, have formed dikes differing in composition from the body of the laccolith. A similar origin of mineralizing solutions is discussed on page 197.

If this explanation is correct it is evident that the amount of differentiation and therefore the abundance of dikes is roughly dependent on the size of the laccolith.

STOCKS AND ALLIED BODIES.

DISTRIBUTION AND CHARACTER.

Stocks are found only in the western part of the State, where they are present in many of the ranges crossed by the igneous belts. (See Pl. IV, in pocket.)

They cut rocks from pre-Cambrian to Tertiary in age, some single stocks or series of stocks intruding nearly all of the formations lying between rocks of these two ages. For example, the stocks of the middle Wasatch extend from pre-Cambrian to Triassic, those of the San Francisco and adjacent regions from Cambrian to Triassic, and those of the Tintic Range from Cambrian sediments to Tertiary lavas. They show no apparent tendency to be more abundant in the rocks of one period than in those of another, though it may be noted that several of the largest bodies are associated with the older rocks, as, for example, the Little Cottonwood and Granite Mountain stocks in the pre-Cambrian rocks and the Ibapah stock of the Deep Creek Range in the pre-Cambrian though extending into the Carboniferous. The large stock of the Mineral Range, however, cuts sediments of Carboniferous and later ages. It is worthy of note that the area in which the stocks occur was probably never covered by the great thickness of Cretaceous shales that covered eastern Utah.

The rocks of the stocks range in texture from typically granitic to typically porphyritic,

not only in different stocks, but in many individuals. It is not confined to the smaller bodies, for the large Ibapah, Little Cottonwood, and Granite Range stocks are characterized by large phenocrysts of feldspar. In some localities, however, the smaller bodies and those intruded nearest the surface apparently tend to porphyritic and the larger and deeper seated bodies to granitic texture. In individual stocks also (in the stock of the San Francisco Range, for instance) the higher or marginal portions may be pronouncedly porphyritic, and the main body of the stock granitic.

COMPOSITION.

General features.—The stocks of the State, like the laccolithic bodies, are as a whole of intermediate composition. They show much greater variation, however, ranging from granite through granodiorite and quartz monzonite to quartz diorite. There is apparently a rather marked relation between the size of a stock and possibly also the depth at which it solidified, and its chemical composition. The larger stocks are generally richer in silica, alumina, potassium, and sodium, and poorer in calcium, magnesia, and iron. This holds true for the Little Cottonwood, Sheeprock Mountain, Desert Mountain, Granite Mountain, Ibapah Mountain, and Mineral Mountain bodies. In general, also, the more siliceous rocks are intruded into the older sediments. This is true of the Little Cottonwood, Sheeprock Mountain, Desert Mountain, Raft River Mountain, Granite Mountain, and Ibapah Mountain stocks, all of which are intruded into Cambrian and pre-Cambrian rocks, though the Ibapah stock probably extended nearly or quite to the Carboniferous.

In the southern belt the most siliceous rocks, those of the Mineral Mountains, are associated with the Carboniferous and Triassic sediments, and the less siliceous rocks (those of the San Francisco Mountains, for instance) are associated with older rocks, intruding Ordovician and possibly older sediments. The San Francisco stock, however, intrudes also Tertiary eruptives, indicating that although associated with older sedimentary rocks it is not a deep-seated body.

The possible significance of the two facts that the more siliceous rocks form the larger intrusive bodies and that they are intruded into the older strata are discussed on page 98.

Analyses.—In the following tables are given the available chemical analyses of rocks from stocks or allied bodies of intrusive rock in the State. Those that seem to illustrate significant variations in composition are assembled in the tables, and a few analyses of extrusive rocks are included for the sake of ready comparison with the associated intrusive rocks.

Analyses of rocks from the Little Cottonwood, Bingham, and Park City stocks and of the extrusive rock of Park City area.

	1	2	3	4	5	6	7	8
SiO_2	67.02	63.46	61.64	59.68	59.35	58.64	57.16	54.23
Al_2O_3	15.78	15.93	14.66	15.61	16.36	15.35	16.69	17.37
Fe_2O_3	1.56	2.61	1.95	2.49	2.90	3.25	3.47	4.00
FeO	2.8	2.31	1.68	2.38	3.36	2.54	2.76	1.95
MgO	1.09	2.27	2.55	2.52	3.08	2.84	2.47	3.00
CaO	3.31	4.33	4.65	4.63	5.03	5.37	5.86	6.67
Na_2O	3.85	3.66	2.71	3.96	3.73	3.60	3.82	2.96
K_2O	3.67	3.49	3.07	2.92	3.85	4.23	4.49	2.80
H_2O-	.29	.27	3.60	2.51	.28	.86	.83	1.60
H_2O+	.63	.74			.64	1.50	1.06	3.71
TiO_2	.37	.62	.48	.62	.87	.83	.87	.75
ZrO_2	.04	.03	.01	.01	.03			.02
CO_2		Trace.	2.15	2.29	Trace.	None.	None.	.33
P_2O_5	.26	.16	.24	.29	.44	.02	.41	.34
S	.03					.05		
MnO	.02	.07	.06	.08	.07	Tr.	Tr.	.10
BaO	.13	.16	.18	.15	.16	.18	.30	.15

1. Granodiorite, Little Cottonwood stock. R. C. Wells, analyst.
2. Quartz diorite, east side of Brighton Gap. W. F. Hillebrand, analyst.
3. Quartz diorite porphyry, Valeo mine, Cottonwood Canyon. W. F. Hillebrand, analyst.
4. Quartz diorite porphyry, dike northwest of Daly-West shaft, Park City district. W. F. Hillebrand, analyst.
5. Quartz diorite, three-fourths of a mile northeast of Clayton Peak. W. F. Hillebrand, analyst.
6. Monzonite, British tunnel, Last Chance mine, Bingham district. E. T. Allen, analyst.
7. Monzonite, Tribune tunnel, Telegraph mine, Bingham district. E. T. Allen, analyst.
8. Andesite, Ontario drain tunnel, Park City district. W. F. Hillebrand, analyst.

Chemical analyses of rocks from the Ibapah stock and from a locality near Gold Hill, Deep Creek Range.

[R. C. Wells, analyst.]

	1	2
SiO_2	70.67	62.84
Al_2O_3	16.24	14.21
Fe_2O_3	.37	.91
FeO	1.15	3.75
MgO	.26	3.04
CaO	1.71	4.72
Na_2O	3.95	2.85
K_2O	4.85	4.60
H_2O-	.29	.26
H_2O+	.64	1.23
TiO_2	.23	.42
ZrO_2		Trace.
CO_2	Trace.	.38
P_2O_5	.11	.41
S	.01	.01
MnO	.03	.06
BaO	.05	.03

1. Granodiorite, Ibapah stock.
2. Quartz monzonite, Clifton district.

Chemical analyses of quartz monzonite from the San Francisco and adjacent districts.

	1	2	3	4
SiO_2	62.10	66.00	64.00	64.41
Al_2O_3	15.47			15.85
Fe_2O_3	2.64			1.95
FeO	3.15			2.52
MgO	2.57	1.13	1.71	1.66
CaO	5.31	3.93	2.95	3.71
Na_2O	3.56	3.60	3.55	3.60
K_2O	3.15	4.01	5.45	3.46
H_2O-	.14			.12
H_2O+	.72			1.09
TiO_2	.81			.46
CO_2	Trace.			.72
P_2O_5	.27			.23
MnO				.07

1. Quartz monzonite, Cactus area, San Francisco district.
2. Quartz monzonite, Beaver Lake district.
3. Quartz monzonite, Star district.
4. Quartz monzonite, O. K. vertical shaft, Beaver Lake district.

Chemical analyses of quartz monzonite and andesite from the Tintic and Iron Springs districts.

	1	2	3
SiO_2	59.76	65.29	63.63
Al_2O_3	15.70	11.57	15.64
Fe_2O_3	3.77	2.10	3.59
FeO	3.30	2.67	.93
MgO	2.16	2.87	2.32
CaO	3.88	4.85	4.46
Na_2O	3.01	2.10	1.70
K_2O	4.40	5.18	5.22
H_2O-	.31		
H_2O+	1.11	2.32	2.10
TiO_2	.87		
CO_2	.78		
P_2O_5	.42	.22	.15
MnO	.12		
BaO	.09	.17	.05
SrO	Trace.		

1. Monzonite. Iron Duke mine, Tintic district.
2. Andesite, east of Granite Mountains, Iron Springs district.
3. Weathered andesite, Desert Mound, Iron Springs district.

An examination of the analyses from the Little Cottonwood, Park City, and Bingham districts shows that the largest body which is associated with the oldest rocks is the most siliceous and is relatively low in calcium, magnesium, and aluminum. Farther to the east, smaller bodies that intrude higher formations are lower in silica and markedly richer in aluminum, calcium, and magnesium. Sodium, potassium, and iron show no very marked differences. The Bingham stock, which intrudes upper Carboniferous rocks, does not differ greatly from the Park City stocks at about the same horizon.

In the accompanying diagram (fig. 8) an analysis of the Bingham rock and the three available analyses from the Cottonwood and Park City districts that are free from carbon dioxide and that evidently represent nearly fresh rocks are plotted to show the relation of the principal oxides to the silica content. The silica in each analysis is plotted as an abscissa and the remaining oxides in each analysis on a single vertical ordinate located by the silica abscissa.[1] The form of the line that connects the points representing an oxide on the several ordinates expresses the variations in the ratio of their oxide to silica.

The analyses thus arranged according to decreasing silica are likewise arranged in order of the age of the rocks in which the stocks are intruded, the more siliceous being in the older rocks. An analysis of the andesite of the Park City area is also plotted, and it falls in fairly well with the series, being higher in alumina and calcium, essentially the same in magnesium, and slightly lower in alkalies and iron.

The analyses representing the stocks in the Deep Creek Range show that the stocks are similar as to age of the intruded rocks and the composition of the intrusive rock, but that they differ through a decrease of alumina in the less siliceous rock and a more pronounced increase in iron.

The Granite Range contains but one large stock, which is distinctly granitic and, with the abundant pegmatite (pegmatite dikes are estimated to occupy 20 per cent of the exposure

[1] Iddings, J. P., Igneous rocks, vol. 1, p. 10, 1909.

over large areas), is probably the most siliceous and most highly alkaline large intrusive body in the State. The Raft River Range stock is similar in composition to the stock of the Granite Range. The main intrusive stock of the Tintic Range is similar in composition to those of the Bingham and Park City districts. Comparison of these widely separated stocks would probably fail to show the fairly regular relationships that obtain between closely associated bodies.

Chemical analyses are not available of the larger stock of the Mineral Range in the southern belt, but it is certainly distinctly more siliceous and lower in calcium and magnesium than those either to the east or west. So far as indicated by present knowledge the change in this belt is similar to that in the central Wasatch and the Deep Creek ranges.

All the stocks in the belt extending through the Iron Springs district were intruded into late rocks and are relatively small. In composition they are similar to the smaller stocks in the younger rocks in other parts of the State.

Causes of differences in composition.[1]—The composition of a molten rock mass or magma can be changed by the solution of rocks of different composition, and by the separation of the magma into portions differing in composition. The first process is called assimilation, the second differentiation.

It is apparent that if a quantity of basaltic rock were dissolved in a magma having the composition of granite the resultant mixture would be more basic, or if quartzite were dis-

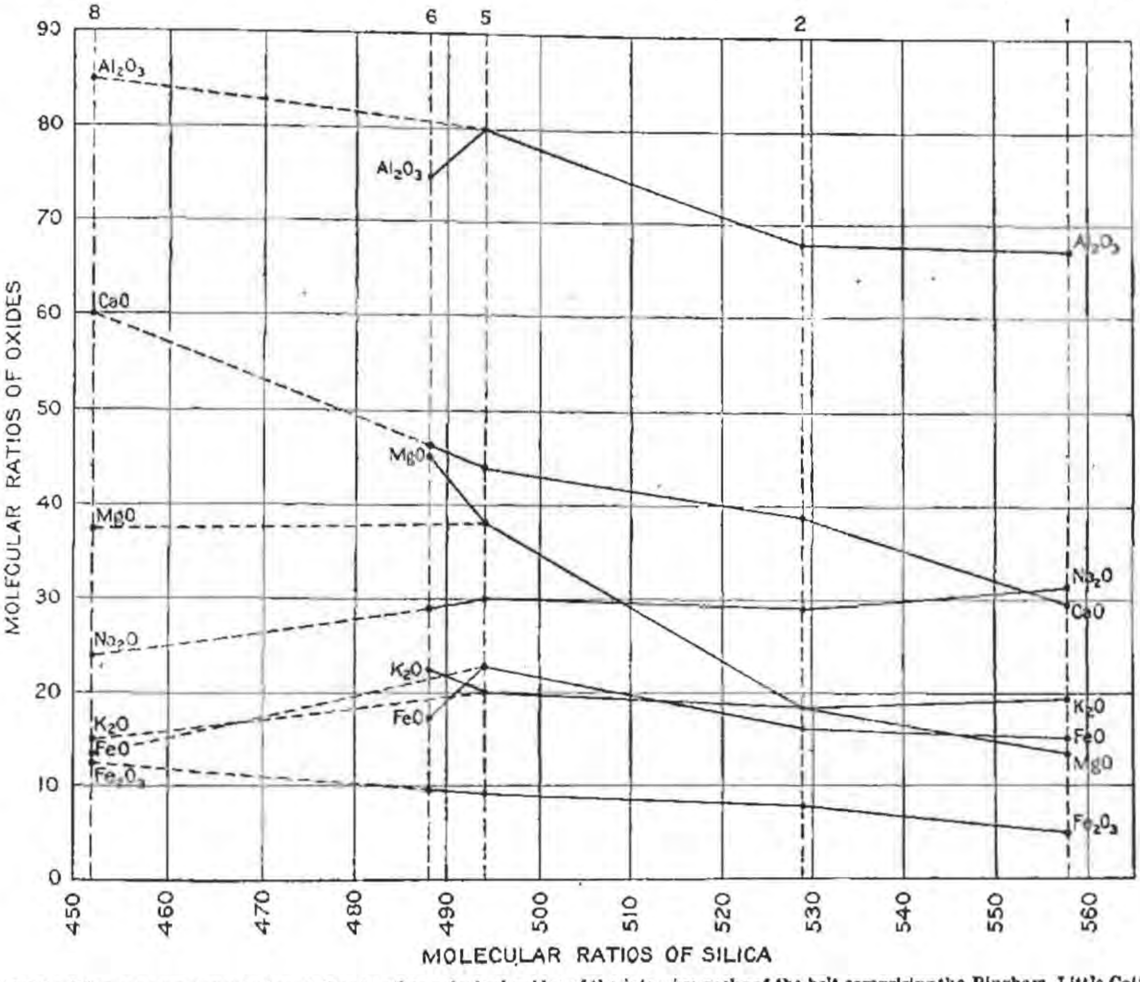


FIGURE 3.—Diagram showing relation of silica to other principal oxides of the intrusive rocks of the belt comprising the Bingham, Little Cottonwood, and Park City districts. 1, Granodiorite, Little Cottonwood stock; 2, quartz diorite, east side of Brighton Gap; 5, quartz diorite, three-fourths of a mile northeast of Clayton Peak; 6, quartz monzonite, British Tunnel, Last Chance Mine, Bingham district; 8, andesite, Ontario drain tunnel, Park City district.

[1] Those desiring a general discussion of this subject are referred to the textbooks, especially to the following: Igneous rocks, by J. P. Iddings; Igneous rocks and their origin, by R. A. Daly; The natural history of igneous rocks, by A. Harker. An especially suggestive discussion based on experimental data has been presented by N. L. Bowen (The later stages of the evolution of the igneous rocks: Jour. Geology, vol. 23, No. 8, suppl., 1915).

solved in a basaltic magma the resultant material would be more siliceous than basalt.

The separation of a magma into portions differing in composition may be thought of as occurring in several ways.

In a fluid magma the heavier portions may settle in a manner similar to the separation of matte and slag in a smelting mixture. On crystallization, basic minerals commonly form earliest. They are heavier than the fluid magma and may settle and at greater depth may dissolve or remain undissolved, thus tending to decrease the basicity of the portion where they were formed and to increase it in the portion where they dissolve or collect. If siliceous minerals form that are lighter than the magma the reverse takes place. If a portion of the magma, as that near the inclosing walls, cools faster than the rest, the basic minerals begin to crystallize first and the composition of the remaining liquid becomes more siliceous. According to the well-known law that a solution tends to become uniform throughout, there would be a movement of the basic constituents toward this area, and a movement of the siliceous constituents away from it. The tendency of this process is to make the rock that crystallizes first more basic than the mass of the magma.

When a magma is largely solidified and consists of a mass of crystals with a small portion of liquid, comparable to gravel saturated with water, the mass itself or the inclosing rocks may be fissured and this liquid portion be squeezed into the fissures. It will have a different composition from the main body of the magma, and it is possible that pegmatite and aplite dikes are frequently formed in this way.

The basic dikes that commonly occur in the intrusive masses may have been forced into the fissured rock from deeper-seated sources where the basic constituents have collected and have not solidified as quickly as the portions nearer the surface.

The intrusive bodies of Utah are believed to have been affected both by assimilation and by differentiation, but the relative importance of these two processes is somewhat doubtful.

Assimilation might explain the relatively siliceous character of the stocks that reach only the older strata as compared with those that penetrate the Carboniferous and later beds; for the older sediments are dominantly siliceous, whereas the younger consist in great part of shale and limestone, whose assimilation would enrich the magma in calcium, magnesium, and aluminum. But similar results may have been produced by differentiation, especially by the settling of heavy crystals. The composition of the original magma in a single intrusive body should be most nearly represented by the material that crystallized earliest. Solidification would take place first in dikes, then in the apices, the peripheral parts, and the minor projections of the magma chamber. In the central and lower parts of the chamber the magma would long remain liquid and subject to differentiation by the sinking of crystals of the ferromagnesium minerals and calcic feldspar, which begin to solidify early and are much heavier than the inclosing magma. The magma would thus become progressively more siliceous and alkaline and poorer in iron, magnesia, and lime.

Of two entirely separate intrusive bodies that were similar in composition, depth, and extent of truncation, the larger would have remained liquid longest and its basic crystals would have settled in greater quantity; the portion of it likely to be exposed by erosion would be more siliceous than the corresponding portion of the smaller stock. Again, of two wholly similar bodies whose walls diverged downward, as appears to be usual, the one most deeply eroded would appear to be both larger and more siliceous than the other.

The settling basic crystals should of course accumulate in depth, and would possibly be re-fused to form a basic magma.

The facts of observation harmonize with this hypothesis. The rocks of the dikes and small bodies are generally more basic than the main bodies with which they are connected, and of separate bodies belonging to a single group the larger are in general the more siliceous. No large bodies of basic rock have been found, but this may be because erosion has not reached them; the hypothetical deep-lying magma may be represented by the basic dikes that are associated with many of the stocks.

The differences of composition observed in the stocks are believed to be due in greater measure to differentiation, probably by the settling of basic crystals, than to assimilation, because comparatively little direct evidence of

assimilation has been observed and because the differentiation hypothesis explains the facts more fully.

The bearing of differentiation in igneous bodies, on the deposition of ores is discussed on page 198.

RELATIONS OF EXTRUSIVE AND INTRUSIVE ROCKS.

The relation of the intrusive and extrusive rocks is not everywhere clear. In some areas extrusion was followed by intrusion, in others intrusion appears to have come first, and in still others the two appear to have been essentially contemporaneous.

Boutwell and Woolsey consider that the extrusion of the large body of andesite occupying the depression between the Wasatch and Uinta ranges was later than the intrusions of the Wasatch Range. The evidence, however, is not entirely conclusive, and that these authors consider that the two were essentially contemporaneous is indicated by their description of the Clayton Peak intrusive body, as follows:[1]

> In like manner the attitude of the Clayton Peak intrusive mass and of the porphyrites in the sediments suggests entrance from the west and progressive movement eastward until the climax was attained in the extensive extrusions of andesite between the Wasatch and Uinta ranges.

The chemical relation of the andesite to the intrusive bodies, as shown in figure 8, seems to support this idea.

In the Bingham district the extrusive rocks are probably the later,[2] but the opportunities for observing the relations are very meager. In the Tintic district [3] the main intrusive bodies are later than the rhyolite and the earlier andesite and are contemporaneous with the latest latites and andesites. In the Tushar Range the intrusive rocks are later than a part of the extrusives. Basalts, however, are latest of all, and some of the rhyolite may be later than the intrusive rock. In the Mineral Range the relations have not been determined, but farther west in the Rocky, Beaver Lake, and San Francisco ranges the main intrusive bodies are believed to be later than most of the extrusives. In the Iron Springs district Leith and Harder consider that the intrusive rocks are earlier than the extrusive ones, but (see p. 571) it seems possible to interpret the relations to mean the opposite. Farther west in Utah the intrusive and extrusive rocks have but rarely been observed in contact and their relation has nowhere been definitely determined.

It thus seems very probable that most of the igneous rocks represent one long general epoch of igneous activity, during which both intrusion and extrusion occurred. Whether this applies to the igneous rocks near the western border of the State is not known.

AGE OF IGNEOUS ROCKS.

The principal volcanic areas of Utah lie almost midway between the Pacific coast region, in which the intrusive rocks are of late Jurassic or early Cretaceous age, and the Rocky Mountain area, in which the monzonitic and allied intrusives are of Tertiary age.

Workers in Nevada have generally considered the large intrusive bodies to be of the same age as those of the Sierra Nevada region, namely, late Jurassic or early Cretaceous. The intrusive bodies of the Plateau region and several of those of the eastern part of the Great Basin region in Utah are with considerable assurance assigned to the Tertiary, and may be correlated with the intrusives of the Rocky Mountain region rather than with those of the coast region. In western Utah, where sedimentary formations later than Carboniferous are absent, there are usually no definite data for determining whether the intrusive rocks should be correlated in age with the rocks on the east or with those on the west.

The time of volcanic activity in the State is perhaps most definitely determined for the High Plateau region. Of this Dutton says:[4]

> The oldest eruptions go back to middle Eocene; the latest can not be as old as the Christian era. It is hard to believe that they are as old as the conquest of Mexico by Cortez. Between the opening and cessation of that activity (if, indeed, it has even yet ceased forever) the eruptions have been intermittent.

[1] Boutwell, J. M., and Woolsey, L. H., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, p. 67, 1912.

[2] Boutwell, J. M., Economic geology of the Bingham mining district, Utah: U. S. Geol. Survey Prof. Paper 38, p. 56, 1905.

[3] Tower, G. W., and Smith, G. O., Geology and mining industry of the Tintic district, Utah: U. S. Geol. Survey Nineteenth Ann. Rept., pt. 3, p. 657, 1899. Also Lindgren, Waldemar, and Loughlin, G. F., Geology and ore deposits of the Tintic mining district: U. S. Geol. Survey Prof. Paper 107, p. 75, 1919.

[4] Dutton, C. E., Report on the geology of the high plateaus of Utah, p. 55, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

There is little doubt that the extensive fields of lava extending westward from the High Plateau into Nevada are essentially contemporaneous with those of the plateaus, and the flows in other parts of the State are probably also of essentially the same age, though the evidence is less conclusive. Several of the intrusive bodies of the State are contemporaneous with the flows (see p. 99), and it is believed that this is true for all those lying along the eastern margin of the Great Basin. Whether it is true of the intrusive bodies near the western border of the State is not known.

Volcanic activity, therefore, apparently broke out in early Tertiary time, and both extrusion and intrusion continued through middle and late Tertiary into recent time, the latest basaltic eruptions having taken place only a few hundred years ago.

STRUCTURE.

Archean rocks are exposed in only relatively small areas, and data are not available for the discussion of their complex structural history. The following description of the structure is, therefore, confined to rocks younger than Archean. The positions and relations of the major structural features are shown in Plate XI.

FOLDS.

Folding, though less conspicuous than faulting in most parts of Utah, is yet of importance. It appears to be greatest in a north-south zone that extends across the State, along the boundary of the Basin and Plateau provinces. In this zone the pre-Tertiary rocks have been thrown into a series of folds, most of which strike north-south but some of which strike from nearly northwest-southeast to considerably east of north.

In southeastern Idaho [1] and southwestern Wyoming,[2] in the northern continuation of this belt, the folds are close, in many places overturned, and are associated with extensive thrust faulting. To the south the folds are more open and the thrust faulting is less important, and south of the southern Wasatch both folds and faults have largely died out, though open folding is recognized much farther to the south. It is probable that the folds that antedate the Tertiary rocks of the High Plateau [3] were produced at the same time as these folds. In the southern part of the State, over a width of several miles, from St. George nearly to Cedar City, a series of north-south open anticlines and synclines, with local overturning of the folds,[4] is conspicuous.

DOMICAL UPLIFTS.

Broad uplifts consisting of an anticlinal folding or doming of the rocks are of prime importance in Utah. These uplifts may be separated into those that show a distinct trend and those that show no marked trend. Among those with a distinct trend are the great east-west Uinta uplift and its westward extension through the Wasatch and Oquirrh ranges, the similar but lesser uplift of the Raft River Range in the northwestern part of the State, and the less clearly defined east-west uplift in the latitude of the Tintic and Deep Creek ranges, in which pre-Cambrian rocks have been raised above the present erosion surface in numerous localities, though not exposed in the adjacent regions either to the north or south. (See Pl. XI.) This structure apparently flattens out before reaching the Tintic Range. Farther south a similar structural feature extends across the Tushar, Mineral, Star, San Francisco, and Wah Wah ranges, and still farther south a series of domical uplifts, associated with intrusions, extends northeast and southwest through the Iron Springs-Bull Valley region.

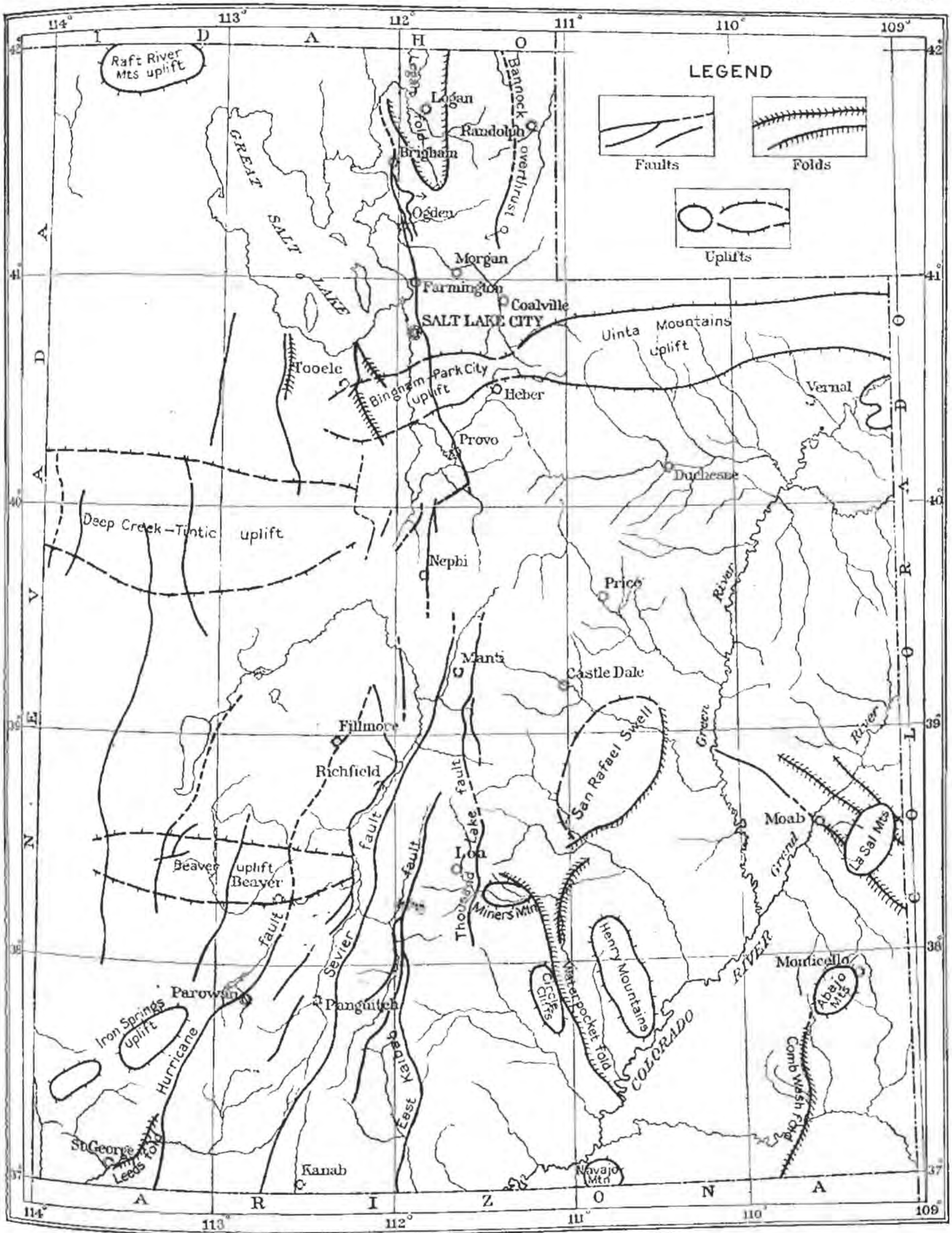
In the southeastern part of the State the San Rafael Swell, Henry Mountains, Abajo Mountains, and Navajo Mountain show less definite trends. The La Sal Mountains, however, form the central portion of a series of northwest-southeast folds several miles long. The Water Pocket flexure consists of an unsymmetrical uplift, of which the eastern limb dips steeply and the western limb gently, and along which the Circle Cliff (Burr Flats) and Miners Mountain swells are subsidiary domes. The great Monument Valley uplift east of Colorado River trends distinctly west of south from the region of the Abajo Mountains into Arizona,

[1] Richards, R. W., and Mansfield, G. R., The Bannock overthrust; a major fault in southeastern Idaho and northeastern Utah: Jour. Geology, vol. 20, p. 704, 1912.

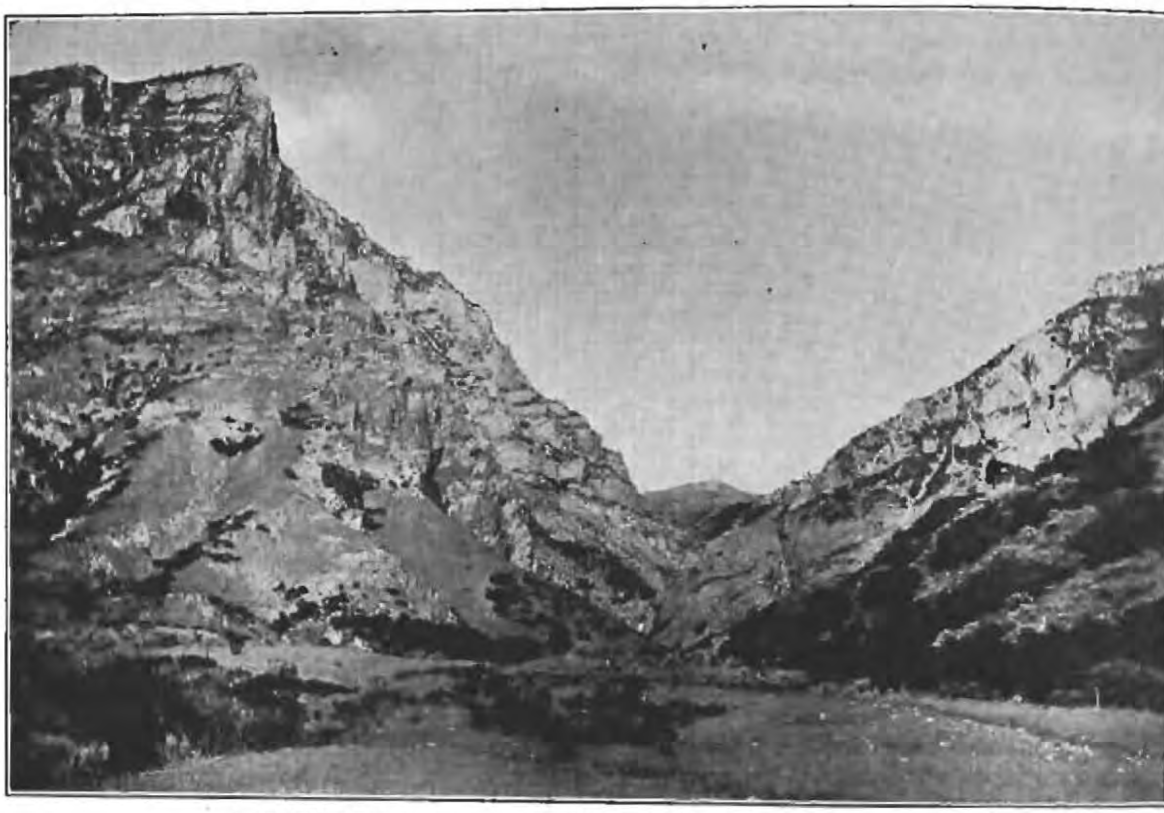
[2] Veatch, A. C., Geography and geology of a portion o southwestern Wyoming: U. S. Geol. Survey Prof. Paper 56, p. 108, 1907.

[3] Dutton, C. E., Geology of the high plateaus of Utah, p. 44, U. S. Geog. and Geol. Survey Rocky Mtn. Region, 1880.

[4] The Hurricane fault in the Toquerville district, Utah: Harvard Coll. Mus. Comp. Zool. Bull., vol. 42, p. 233, 1914.



POSITION AND RELATION OF MAJOR STRUCTURAL FEATURES OF UTAH.



A. RECENT FAULT ALONG WASATCH MOUNTAIN FRONT NEAR PROVO.

B. HANGING VALLEY IN SHEEP ROCK RANGE, PROBABLY FORMED BY RECENT FAULTING.

and the Henry Mountains group trends distinctly southeast. The San Rafael Swell is less definite, though the sharp eastern flexure, its most conspicuous structural feature, trends northeasterly, as does also the general elongation of the swell.

In the western part of the State faulted domes that are in many respects similar to

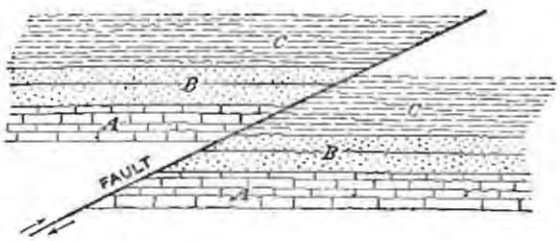


FIGURE 9.—Relation of the rocks on opposite sides of a reverse fault.

the smaller domes of eastern Utah are present at Ophir, in the Oquirrh Range, and near the American Fork Canyon, in the Wasatch Range.

FAULTS.

Faults are important, both in their relation to large topographic features and to metalliferous and other mineral deposits.

For convenience in description they may be separated into reverse or overthrust faults, which resulted from compression that broke the rocks and pushed one portion over the other (fig. 9), and normal faults, which resulted from areal extension that broke the rocks and allowed one portion to slip down past the other (fig. 10). Reverse and normal faults are commonly if not invariably of different ages.

REVERSE AND OVERTHRUST FAULTS.

The reverse and overthrust faults are largely confined to the areas of rather close folding and to areas adjacent to igneous intrusions. Like the close folds they are most abundant north of Utah in Idaho and Wyoming but extend southward into Utah. One has been traced for many miles nearly due south from Bear Lake, and others have been recognized in the Wasatch Range, notably between Willard and Ogden, in the Cottonwood-Park City region, in the West Butte mining district, and as far south as Mount Nebo. Little detailed geologic work has been done in the Wasatch Range and there is little doubt that overthrust faults are more abundant there than is at present known.

Locally reverse or overthrust faulting has resulted from the pushing aside of earlier rocks to make room for the stocks. Such faulting has been recognized in the Park City and Little Cottonwood districts and is probably present in other localities.

NORMAL FAULTS.

Normal faults are very abundant in Utah and many of them are remarkable for the scores and even hundreds of miles that they can be traced and for their great vertical displacement. (See Pl. XI.) Many if not all of the ranges of western Utah are believed to be outlined by them, and farther east they are strongly marked by such physiographic features as the great Hurricane scarp.

In general, displacement has apparently been less in the eastern than in the western part of the State. In the faults associated with the Basin Ranges it is commonly large; in the Plateau region it is far less noticeable, some folds passing into monoclinal flexures, the displacement not having been sufficient to cause actual rupture. In some places this failure to break may have been due to the character of the rock, for shales are far more prevalent in the Plateau region, but there can be little

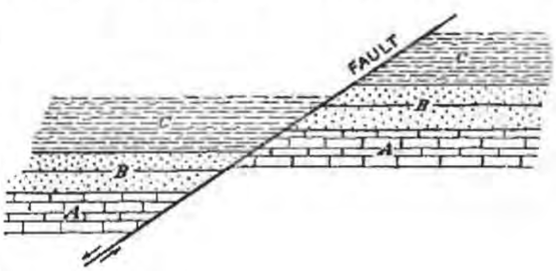


FIGURE 10.—Relation of the rocks on opposite sides of a normal fault.

doubt that the displacement in general decreases toward the east.

TREND.

Most of the faults trend generally south (see Pl. XI) but finally swing westward, paralleling the boundary between the Plateau and Basin provinces, which, indeed, is mainly determined by faults.

In the western part of the Plateau province the faults converge toward the north and diverge toward the south. Dutton [1] has called attention to this convergence, stating that "several of the grander faults at length become

[1] Op cit., p. 27, 1880.

merged into one vast monoclinal flexure, forming the western flank of the Wasatch Plateau." It seems not improbable that the great displacement represented by the Wasatch fault to the north is distributed among several faults farther to the south.

East-west normal faulting is far less conspicuous than north-south faulting but is important, especially in the Basin province. Where these east-west faults cross the ranges they show large displacements, as in the San Francisco Range, where a thick series of lavas are thrown against early Paleozoic sediments, the relatively depressed block being to the south. A similar relation exists in the Mineral Range. Detailed work in the Basin Ranges of Utah will doubtless show the east-west faults to be rather abundant.

RELATIONS OF THE DIFFERENT STRUCTURAL TYPES.

The relations of the different structural types are not everywhere clear, but viewed as a whole the sequence of events appears to be rather definite.

The north-south folds are with little doubt the earlier and are contemporaneous with the overthrust faulting, both having resulted from the forces tending to compress the area in an east-west direction. East-west uplifts like the Uinta uplift are younger than the north-south folding and overthrust faulting, as is shown by the fact that these structures are affected where crossed by the extension of the Uinta uplift in the Wasatch Range. East-west uplifts farther south than the Uinta Range are less conspicuously connected with the north-south folds, but in the San Francisco Range at least the evidence shows that they are the younger.

The relation of the domical uplifts in southeastern Utah to the east-west uplifts farther west has not been established. Both, however, were connected with igneous activity, which gives some reason for supposing that they were essentially contemporaneous.

That the normal faults are the latest important structural feature of the region is repeatedly shown by their cutting across the other structures. Thus many faults outlining the Basin Ranges cut across the folds in those ranges. The great Wasatch fault crosses the westward extension of the Uinta uplift, and other faults, notably those of the Mineral and San Francisco ranges, cross the Tushar-San Francisco uplift.

All normal faults are not of the same age, and not a few of them have been the locus of repeated movements. Normal faulting began some time after the folding and east-west uplifts and is probably still in progress along some of the faults.

GEOLOGIC AGE OF STRUCTURAL FEATURES.

The geologic age of many of the structural features is difficult to ascertain, owing to the absence over a large part of the region of the later sedimentary rocks. This is especially true in the Great Basin region in Utah where, for the most part, there are no well-exposed sedimentary formations between Paleozoic and Recent.

That changes in the level of the land were frequent throughout Paleozoic time is indicated by different thicknesses of the formations, showing deposition, nondeposition, and erosion. The slightness of the angular unconformities in the sedimentary rocks throughout the Paleozoic and Mesozoic in Utah suggests that the changes that occurred through these eras, especially in the central part of the State, were in the nature of low domings and did not involve important folding or faulting. The north-south folds and overthrust faults involved Cretaceous and probably early Tertiary rocks and are believed to have been formed in post-Cretaceous or early Tertiary time. In Utah the early Tertiary rocks are apparently less intensely folded than the Cretaceous. In most of the Basin Ranges the Mesozoic sediments are absent, and it is therefore impossible by direct evidence to determine the age of the folding closer than post-Carboniferous. It is possible, therefore, that some of the folding occurred at the time of the uplift at the close of the Carboniferous or that the great post-Jurassic upheaval along the Pacific coast affected the rock as far east as Utah and that some of the folding is to be ascribed to that period. However this may be, all the folds whose age can be rather definitely determined were formed during the post-Cretaceous uplift, and there is no recognized evidence that the folds whose age has not been determined were not

of the same period. Ransome[1] has reviewed the evidence of this folding, and concerning the much discussed question of its age he says:

Toward the close of Cretaceous time, the oscillations recorded in the character of the Laramie sediments indicate the approach of diastrophic conditions. In the northern section of the Rocky Mountain region, the principal deformation appears to have taken place at the close of the Fort Union; along the eastern side of the Front Range in Colorado the decisive movement has been interpreted as having taken place at the close of the Laramie and before the deposition of the Arapahoe beds. At the south end of the Rocky Mountains strong unconformities have been described both above and below the Nacimiento group, which means that notable deformation and erosion occurred at the close of the Cretaceous and again just before the deposition of the Wasatch Eocene. In the northwestern part of the Park Range Province, there was uplift and vigorous erosion at the close of the Cretaceous and renewed uplift after the deposition of the Wasatch and Green River beds.

Apparently the movements of the Laramide revolution were not of the same intensity in all parts of the Laramide system at the same time, and the accurate correlation of these movements is still a work for the future requiring much more detailed and comprehensive study than has yet been given to this problem. It is clearly not safe to assume that an unconformity observed in any one locality in this vast province is indicative of movement provincial in its extent.

The boundary between the Basin and Plateau provinces in general also marks the boundary between the Cretaceous areas of erosion and sedimentation, and it is perhaps significant that the most folding and thrust faulting occurred in this zone.

The age of domical uplifts later than the folds is not very closely ascertained, and indeed they may not all have occurred at the same time. They were evidently closely associated with the igneous activity of the region, which has probably been in progress from early Tertiary to Recent time.

The intrusions of the Park City and Little Cottonwood districts are believed by Boutwell to have occurred in early Tertiary, and the Uinta uplift is probably contemporaneous with these. Some of the intrusions farther south with which the uplifts are associated are notably younger, for they cut lavas believed to be at least as late as middle Tertiary.

The age of the domical uplifts in the southeastern part of the State is not easy to determine closely. They are post-Cretaceous, and most investigators have regarded them as probably early to middle Tertiary, though the evidence for fixing the date closer than post-Cretaceous is very meager.

Normal faulting has continued over a long period and the time of its beginning is uncertain. It has been important, in very recent time, as is shown by Gilbert[2] for the Wasatch Range, and is suggested by hanging valleys in the Sheeprock Range. (See Pl. XII.) It is also indicated for some of the ranges of southern Utah by recent earthquakes, notably by that of November, 1901, which affected the area along the border of the Plateau and Basin Range provinces in southern Utah. The Weather Bureau says of this earthquake: "On the night of November 13 (1901), Utah experienced the most severe earthquake that has occurred since its settlement. The area affected by this disturbance can be inclosed by a triangle of which the southern boundary of the State is the base and Salt Lake City the apex. The shock was quite severe over an area comprising Sevier, Wayne, Garfield, and the eastern portion of Juab, Millard, and Beaver counties." The evidence is convincing that normal faulting took place in Recent and late Tertiary time, though at what time in the Tertiary it began is unknown.

ORIGIN OF THE STRUCTURAL FEATURES.

NORTH-SOUTH FOLDS AND OVERTHRUST FAULTS.

That the north-south folds and overthrust faults were produced by pressure from the west that tended to compress the region is indicated by the attitude of the folds and the direction of most of the overthrusts. Ransome,[3] who has recently discussed the hypotheses offered in explanation of Cordilleran Mountain structure, says:

It has been a rather widely held tenet among geologists that most of the great mountain ranges of the globe have been formed by thrust from the nearest ocean basin, the classic example being the Appalachians. It has also been believed by many that the Laramide system is essentially Pacific in origin and that the deformation which gave it birth was the consequence of interaction between the Pacific Basin and the continental margin. Daly, as previously noted, maintains this view, which was also that of G. M. Dawson. * * * Keeping fully in mind the speculative and tentative nature of the suggestion, we may suppose that in Cretaceous time the Cordilleran

[1] Ransome, F. L., The Tertiary orogeny of the North American Cordillera and its problems: Problems of American geology, pp. 360–361, 1915.

[2] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, 1890.

[3] Op. cit., p. 364.

land mass was rising and was being eroded. In accordance with the general principles enunciated by Suess and Chamberlin, the rising mass probably had a tendency to spread laterally, particularly to the east where sediments had previously accumulated to enormous thickness in the Laramide trough, derived doubtless from older land masses which occupied in part the position of the Cretaceous land. For a time, as Chamberlin[1] has pointed out, the effect of this creep of the protuberant mass would be to favor sedimentation by pushing the sea shelf outward and slightly downward. As uplift of the land mass and sedimentation of the adjoining area continued resistance to lateral spread would diminish. Erosion, by cutting down the land, would tend to delay the final diastrophic event; but deposition, the complement of erosion, would tend to hasten it. Finally, if the forces causing the uplift of the land area were relaxed, by just so much as the underlying support of the protuberant arch was lessened would thrusting stresses accumulate along the borders of the land mass. Relief of these presumably would be accomplished by a thrusting forward of the land mass against the sediments to the east, the crumpling of these into folds, and their further deformation by thrust faulting. This diastrophic revolution it is to be expected would be followed by collapse and down-sinking of the imperfectly supported Cretaceous continent and by normal faulting behind the overthrusts.

Many of the domical structures, as already indicated, are visibly closely associated with bodies of intrusive rocks, and such an association is probable in others where the intrusive bodies are not exposed. It is not everywhere entirely clear, however, whether the domes were the result of the forcible injection of material with a consequent raising of the overlying rocks or to some other cause which relieved the pressure and permitted the igneous material to enter. The Henry Mountains seem to offer no escape from the conclusion that their injected material was under sufficient pressure to lift the overlying sediments, as has been pointed out by Gilbert. The La Sal Mountains, however, though in most respects similar to the Henry Mountains, are near the center of a series of northwest-southeast folds (see Pl. XI, p. 100), which suggest lateral compression and may have been a factor in the intrusion, though there can be little doubt that the intrusive force was very great. Likewise in the east-west zones of uplift and intrusion it is possible that the uplift may have been primarily due to pressure at right angles to the trend, and that the starting of the uplift may have determined the location of the intrusive bodies. The Uinta uplift (except in the western extension) shows no surface evidence of igneous forces. Its general character, however, is rather strikingly similar to that of the Raft River Range, where the uplift was very evidently associated with igneous activity.

The stocks, like the laccolithic bodies, offer abundant evidence that the material forming them was under pressure sufficient to cause local doming and overthrust or reverse faulting. The discussion of the ultimate cause of this injection force would lead far into the field of speculation, but it is at least reasonably certain that at the time of the domical uplifts and intrusion certain forces were tending to raise the region.

NORMAL FAULTS.

Two explanations for the normal faults have been offered. One, advanced first by Gilbert[2] and adopted by numerous other writers, supposes that the region was broken into a series of blocks by vertical pressure from below. Gilbert considers that this might be brought about by a deep-seated force that would fold the deeply buried rocks and fault those near the surface.

The other explanation, advanced first by Le Conte[3] and also adopted by others, supposes that the faulting has resulted from a settling and collapse of the region, which caused it to break into blocks that settled irregularly. Le Conte supposes that the region was raised by volcanic forces and that when this upward pressure was relieved by the extrusion of vast amounts of lava, the weight of which was added to the overlying portion, subsidence of the whole region occurred. Ransome,[4] who has recently reviewed the evidence on this subject, agrees with Le Conte that the structures were produced by a collapse of the region rather than an elevation, but sees no reason for supposing that any elevation by volcanic forces preceded the collapse. The writer, in accounting for the structure in the San Francisco region,[5] bases an explanation similar to that of Le Conte on the effect of intrusions and extrusions which apparently accompanied the east-west uplift

[1] Chamberlin, T. C., Diastrophism and deformative processes: Jour. Geology, vol. 21, p. 585, 1913.

[2] Report on the geology of portions of Nevada, Utah, California, and Arizona: U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, pt. 1, p. 60, 1875.

[3] Le Conte, Joseph, On the origin of normal faults and of the structure of the Basin region: Am. Jour. Sci., 3d ser., vol. 38, pp. 257-263, 1889.

[4] Ransome, F. L., op. cit., p. 343.

[5] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, p. 27, 1913.

shortly before the faulting. The smaller uplifts (domes) may well have been formed after the forces that had raised the general region had reached a maximum, and the breaking through of the igneous material into the upper strata and out to the surface had inaugurated a collapse.

That the normal faulting was a result of the settling of the region seems the most rational explanation. Similar structural relations may be observed on a pond where the water has drained from beneath a sheet of ice. In settling, the ice sheet forms monoclinal folds which pass into faults, faults of small displacement come together in faults of greater displacement, and where settling is pronounced a structure comparable to that of the Basin Ranges may develop.

It has been generally recognized by workers in the Basin Range and Plateau provinces that the structures of the two areas grade into one another and have a common origin. It is reasonable to suppose that the Basin Ranges represent the more intense action of the same character of forces that have produced the Plateau structure. If this be supposed to be a settling of an uplifted area, the settling in the Basin province has been much more pronounced than that in the Plateau province, a conclusion which is in accord with the stratigraphic evidence.

MINERALOGY.

MINERAL SPECIES.

The large number of metals and the variety in the character of the ore deposits of Utah have resulted in the presence of many mineral species. Most of the metals occur both in minerals like the sulphides and arsenides, in which they were originally deposited, and in minerals like the sulphates and carbonates, formed by the oxidation of the primary minerals.

In the discussion of the minerals the arrangement in Dana's "System of mineralogy" is followed, but an alphabetic list is given below for convenient reference.

Minerals associated with the metal deposits of Utah.

Actinolite (amphibole).
Adamite.
Alunite.
Amphibole.
Andalusite.
Andradite (garnet).
Anglesite.
Anhydrite.
Ankerite.
Annabergite.
Apatite.
Aragonite.
Argentite.
Arsenobismite.
Arsenopyrite.
Aurichalcite.
Autunite.
Axinite.
Azurite.
Barite.
Beaverite.
Beryl.
Beudendite.
Bindheimite.
Biotite.
Bismite.
Bismuth.
Bismuthinite.
Bismutite
Bixbyite.
Borickite.
Bornite.
Bournonite.
Brochantite.
Brucite.
Calamine.
Calcite.
Carnotite.
Celestite.
Cerargyrite.
Cerusite.
Chabazite.
Chalcanthite.
Chalcedony.
Chalcocite.
Chalcophyllite.
Chalcopyrite.
Chenevixite.
Chlorite.
Chrome garnet (uvarovite).
Chromite.
Chrysocolla.
Cinnabar.
Clinoclasite.
Conichalcite.
Connellite.
Copper.
"Copper pitch ore."
Corkite.
Cosalite.
Cotunnite.
Covellite.
Crandallite.
Cuprite.
Cuproscheelite.
Danburite.
Daubreeite.
Descloizite.
Diaspore.
Diopside (pyroxene).
Dolomite.
Dufrenoysite.
Embolite.
Enargite.
Enstatite (pyroxene).
Epidote.
Erinite.
Famatinite.
Fluorite.
Galena.
Garnet.
Geocronite.
Goethite.
Gold.
Goslarite.
Greenockite.
Gypsum.
Hematite.
Heulandite.
Hornblende (amphibole).
Hydrozincite.
Ilmenite.
Jamesonite.
Jarosite.
Kaolinite.
Kermesite.
Lead oxychloride(unnamed).
Laumontite.
Leadhillite.
Lettsomite.
Leverrierite (racewinite).
Limonite.
Linarite.
Ludwigite.
Magnesite.
Magnesolugwigite.
Magnetite.
Malachite.
Malanterite.
Manganite.
Marcasite.
Massicot.
Melaconite.
Mercury.
Mica.
Mimetite.
Minium.
Mixite.
Molybdeuite.
Molybdite.
Monticellite.
Muscovite (white mica).
Octahedrite.
Olivenite.
Onofrite.
Opal.
Orpiment.
Orthoclase.
Pearceite.
Periclase.
Pharmacosiderite.

Minerals associated with the metal deposits of Utah—Continued.

Phlogopite (magnesian mica).	Realgar.	Stibnite.	Tyuyamunite.
Phosgenite.	Rhodochrosite.	Stolzite.	Uranospinite.
Pintadoite.	Rhodonite (manganese pyroxene).	Sulphur.	Utahite.
Plagioclase.	Rutile.	Sylvanite.	Uvanite.
Platinum.	Scheelite.	Talc.	Uvarovite (chrome garnet).
Plumbojarosite.	Scorodite.	Tennantite.	Vanadinite.
Powellite.	Sericite.	Tenorite.	Variscite.
Proustite.	Serpentine.	Tetrahedrite.	Vesuvianite.
Pyrargyrite.	Siderite.	Thaumasite.	Volborthite.
Pyrite.	Silver.	Tiemannite.	Willemite.
Pyrolusite.	Smithsonite.	Titanite.	Wollastonite (pyroxene).
Pyromorphite.	Spangolite.	Topaz.	Wulfenite.
Pyroxene.	Sphalerite.	Tourmaline.	Wurtzite.
Pyrrhotite.	Spinel.	Tremolite (amphibole).	Zeunerite.
Quartz.	Stephanite.	Tungstenite.	Zircon.
		Tyrolite.	Zoisite.

NATIVE ELEMENTS.

Sulphur.—Sulphur has been recognized in the oxidized ores in the San Francisco and Star districts and in small amounts in the ores of the Tintic and Santaquin districts. It also occurs at several localities where it is not associated with metal deposits, notably in eastern Beaver County,[1] in San Rafael Canyon, on the east side of San Rafael Swell,[2] near Virgin River south of Toquerville, and at other localities.

Bismuth.—Native bismuth occurs in the Clifton and Tintic districts and is reported from the Detroit district. It probably occurs in other districts where bismuth minerals are present.

Gold.—Gold has been recovered from placers in Bingham Canyon on Green, Colorado, and San Juan rivers, around the La Sal and Henry mountains, and to a slight extent at other localities. It occurs more or less in most of the lode deposits of the State and is the most important constituent in those of the Mercur, Park Valley, and Spring Creek districts, and in some of the deposits of the Tushar Range, Gold Springs, State Line, and Clifton districts.

Silver.—Native silver is probably present in small amounts in the oxidized ores at numerous localities but is rarely of much commercial importance. It is reported in considerable amount in some of the ores of the Silver Reef district, and it has been recognized in ores from the Star and Tintic districts.

Copper.—Native copper, like silver, is probably present in small amounts at numerous localities, but nowhere has it been of large commercial importance. It has been noted from the San Francisco, Star, Beaver Lake, Tintic, Morgan, and Lucin districts.

Mercury.—Native mercury is reported from several mines in the Gold Springs district.

Platinum.—Native platinum has been noted in the Colorado and Green river placers. Platinum is present in the copper ores of the Bingham and probably of other districts, but whether it occurs native or in combination is not known.

SULPHIDES, SELENIDES, TELLURIDES, ARSENIDES, AND ANTIMONIDES.

Realgar.—Realgar, arsenic monosulphide, AsS (sulphur, 29.9 per cent; arsenic, 70.1 per cent), has been observed in the Mercur and Bull Valley districts and is probably present at other localities.

Orpiment.—Orpiment, arsenic trisulphide, As_2S_3 (sulphur, 39 per cent; arsenic, 61 per cent), occurs in the same localities as realgar.

Stibnite.—The largest deposits of stibnite, antimony trisulphide, Sb_2S_3 (sulphur, 28.6 per cent; antimony, 71.4 per cent), that have been developed are those at Antimony, Coyote Creek, Garfield County. Small deposits have been found in the Bull Valley district and small amounts of the mineral noted in the ores of the Mercur and other districts.

Bismuthinite.—Bismuthinite, bismuth trisulphide, Bi_2S_3 (sulphur, 18.8 per cent; bismuth, 81.2 per cent), occurs in contact deposits in the Mineral Range and in replacement veins in limestone in the Clifton and Star districts.

Molybdenite.—Molybdenite, molybdenum disulphide, MoS_2 (sulphur, 40 per cent; molybde-

[1] Lee, W. T., The Cove Creek sulphur beds, Utah: U. S. Geol. Survey Bull. 315, pp. 485–489, 1907.

[2] Hess, F. L., A sulphur deposit in San Rafael Canyon, Utah: U. S. Geol. Survey Bull. 530, pp. 347–349, 1913.

num, 60 per cent), occurs in small amount in replacement veins in quartz monzonite, notably in the O. K. mine, Beaver Lake district; in contact gold deposits in the Clifton district; in disseminated copper deposits in the Bingham district; in contact deposits in the Mineral Range; and in veins cutting granodiorite in the Little Cottonwood district. Molybdenum minerals present in several other districts have probably resulted from the oxidation of molybdenite.

Tungstenite.—Tungstenite, WS_2 (tungsten, 75 per cent; sulphur, 25 per cent). The only known occurrence of this mineral is in the ores of the Old Emma mine of Little Cottonwood district, where it is found in small amount in lead-silver ores. It is one of the latest sulphides to be deposited and apparently in part replaces earlier minerals.

Galena.—Galena, lead sulphide, PbS (sulphur, 13.4 per cent; lead, 86.6 per cent), is the most important primary lead mineral in all of the lead deposits of the State.

Argentite (silver glance).—Argentite, silver sulphide, Ag_2S (sulphur, 12.9 per cent; silver, 87.1 per cent), is important in the unoxidized ores of the Silver Reef district. It has been recognized in the gold-silver veins of the Tushar Range, in the Horn Silver mine of the San Francisco district, and in the Tintic district. Possibly the silver in much of the argentiferous galena is present as microscopic argentite.

Chalcocite.—Chalcocite, cuprous sulphide, Cu_2S (sulphur, 20.2 per cent; copper, 79.8 per cent), is present in most of the copper deposits of the State. It was the principal copper mineral in the Dyer mine in the Uinta Range, is important in the disseminated copper deposits of the Bingham district, and is present in different amounts in other deposits of the State. It usually occurs as a replacement of other sulphides.

Sphalerite (zinc blende, blende, blackjack).—Sphalerite, zinc sulphide, ZnS (sulphur, 33 per cent; zinc, 67 per cent), is the most important primary zinc mineral in the ores of the State. It occurs in important amounts in the Park City, Little Cottonwood, Bingham, Stockton, Ophir, San Francisco, and Star districts, and is present in most of the others.

Tiemannite.—Tiemannite, mercuric selenide, HgSe, occurs in the Lucky Boy mine near Marysvale, Utah.

Onofrite.—Onofrite, Hg(S,Se), occurs with tiemannite in the Lucky Boy mine.

Cinnabar.—Cinnabar, mercuric sulphide, HgS (sulphur, 13.8 per cent; mercury, 86.2 per cent), occurs in the gold deposits of the Mercur district.

Covellite.—Covellite, cupric sulphide, CuS (sulphur, 33.6 per cent; copper, 66.4 per cent), is abundant in the copper ores of the Horn Silver mine, San Francisco district. It also occurs in the O. K. mine, Beaver Lake district, in the disseminated deposits of the Bingham district, in the Tintic district, and has been recognized from other districts everywhere as a replacement of other sulphides.

Greenockite.—Greenockite, cadmium sulphide, CdS (sulphur, 22.3 per cent; cadmium, 77.7 per cent), occurs as films on sphalerite from the Moscow mine, Star district.

Wurtzite.—Wurtzite, zinc sulphide, ZnS (sulphur, 33 per cent; zinc, 67 per cent), is abundant in the zinc ores of the Horn Silver mine and has been recognized from the Clyde mine in the Tushar Range. In the Horn Silver ores it is regarded as secondary, but in the Clyde ores it appears to be primary.

Pyrrhotite.—Pyrrhotite, sulphide of iron, Fe_5S_6 to $Fe_{16}S_{17}$ (sulphur, about 40 per cent; iron, 60 per cent), is reported from the bedded deposits in the Bingham district and is probably present in other districts but is nowhere known to be abundant.

Bornite.—Bornite, sulphide of copper and iron, Cu_5FeS_4 (sulphur, 28.1 per cent; copper, 55.5 per cent; iron, 16.4 per cent), is nowhere abundant but has been recognized in the contact gold ores of the Clifton district; in the Bingham and Ophir districts; in the Imperial mine, San Francisco district; in the Dolly Varden mine, White Canyon; and in the Mountain View, Steamboat, and other mines of the Cottonwood district.

Chalcopyrite (copper pyrites).—Chalcopyrite, sulphide of copper and iron, $CuFeS_2$ (sulphur, 35 per cent; copper, 34.5 per cent; iron, 30.5 per cent), is the most abundant primary copper mineral in the State, and is present in most districts. Particularly fine specimens of chalco-

pyrite crystals occur in the Cactus mine, San Francisco district.

Pyrite.—Pyrite, iron disulphide, FeS_2 (sulphur, 53.4; iron, 46.6 per cent), is an important primary mineral in practically all of the western districts of the State.

Marcasite.—Marcasite, iron disulphide, FeS_2 (sulphur, 53.4 per cent; iron, 46.6 per cent), occurs as a replacement of carbonaceous material in the "red beds" of the Plateau region and is associated with oxidized copper ore in limestone in the Morgan district.

Arsenopyrite (mispickel.)—Arsenopyrite, sulpharsenide of iron, FeAsS (arsenic, 46 per cent; sulphur, 19.7 per cent; iron, 34.3 per cent), though nowhere present in great abundance has been recognized in the ores of the Clifton, West Tintic, Park Valley, Bingham, and Stockton districts.

Sylvanite.—An undetermined telluride of gold and silver that occurs in the ores of the Tushar Range and in the State Line district is possibly sylvanite, telluride of gold and silver $(Au,Ag)Te_2$, though material suitable for positive determination is not available. Selenium is usually present in the specimens, as well as tellurium, but whether in the same mineral has not been determined.

SULPHOSALTS.

Jamesonite.—Jamesonite, $Pb_2Sb_2S_5$ (sulphur, 19.7 per cent; antimony, 29.5 per cent; lead, 50.8 per cent), has been recognized in the ores of the Park City and West Tintic districts, and in the Horn Silver mine, San Francisco district.

Dufrenoysite.—Dufrenoysite, $2PbS.As_2S_3$, is reported by Maryland Bixby from the San Francisco district.

Cosalite.—Cosalite, $2PbS.Bi_2S_3$, occurs in small amount in the ores of the Cactus mine, San Francisco district.

Bournonite.—Bournonite, $(PbCu_2)_3.Sb_2S_6$ (sulphur, 19.8 per cent; antimony, 24.7 per cent; lead, 42.5 per cent; copper, 13 per cent), is reported from the Silver King and Daly-West mines, Park City district, and from the Little Cottonwood district.

Pyrargyrite.—Pyrargyrite, $Ag_3.SbS_3$ (sulphur, 17.8 per cent; antimony, 22.3 per cent; silver, 59.9 per cent), occurs in the ores of the Horn Silver mine, San Francisco district, and probably at other localities.

Proustite.—Proustite, Ag_3AsS_3 (sulphur, 19.4 per cent; arsenic, 15.2 per cent; silver, 65.4 per cent), is reported by Maryland Bixby from the San Francisco district and by Lindgren from the Tintic district.

Tetrahedrite.—Tetrahedrite, of variable composition but essentially $Cu_8Sb_2S_7$ (sulphur, 23.1 per cent; antimony, 24.8 per cent; copper, 52.1 per cent), is abundant in the ores of the Park City, Cottonwood, and American Fork districts, and rather abundant in the lead ores of the Bingham district. It is present in the ores of the Stockton and East Tintic districts, in the Cactus mine, of the San Francisco district, and in some of the gold-silver veins of the Tushar Range. Specimens of tetrahedrite from the Park City district contain notable amounts of zinc; and some specimens from the Little Cottonwood district contain lead.

Tennantite.—Tennantite, essentially $Cu_8As_2S_7$ (sulphur, 25.5 per cent; arsenic, 17 per cent; copper, 57.5 per cent), occurs in the Tintic district.

Stephanite.—Stephanite, Ag_5SbS_4 (sulphur, 16.3 per cent; antimony, 15.2 per cent; silver, 68.5 per cent), occurs in the ores of the Tintic district.

Geocronite.—Geocronite, $5PbS.Sb_2S_3$, occurs as fine veinlets in galena from the 300-foot level of the Colorado mine, Tintic district.

Enargite.—Enargite, Cu_3AsS_4 (sulphur, 32.6 per cent; arsenic, 19.1 per cent; copper, 48.3 per cent), is abundant in the primary ores of the Tintic, is present in the Little Cottonwood district, and is probably present in the primary ores of other districts, notably the Clifton, that contain abundant arsenic and copper in their oxidized ores.

Famatinite.—Famatinite, Cu_3SbS_4, is intimately associated with enargite in the apex ore body of the Mammoth mine, Tintic district.

Pearceite.—Pearceite, $9Ag_2S.As_2S_3$, occurs microscopically intergrown with galena in the "Gem Channel," levels 14 to 19, of the Gemini mine, Tintic district.

HALOIDS.

Cerargyrite (horn silver, silver chloride).—Cerargyrite, AgCl (chlorine, 24.7 per cent; silver, 75.3 per cent), is one of the important silver minerals and is present in many and probably most of the oxidized silver deposits of

the State. It is especially abundant in the ores of the Tintic, Ophir, San Francisco, and Silver Reef districts.

Embolite.—Silver chlorobromide, Ag(BrCl), and other bromides of silver are frequently reported from the mines of Utah, but most of them have proved to be some other mineral. It is possible and perhaps probable that embolite or bromyrite (AgBr) are present in the ores of the State in small amount.

Cotunnite.—Cotunnite, $PbCl_2$, may be present in the complex oxidized ores of the Tintic district.

Fluorite.—Fluorite, CaF_2 (fluorine, 48.9 per cent; calcium, 51.1 per cent), occurs as a contact mineral in the Mineral Range and the Star district; as a gangue mineral in gold veins in the Tushar Range and Gold Springs district; as a gangue mineral with sphalerite in zinc ores in the Trout Creek district, Deep Creek Range; with chalcopyrite and pyrite in the Erickson district; and in the Wasatch Range east of Ogden.

Daubreeite.—Daubreeite, $2Bi_2O_3.BiCl_3.3H_2O$, has been determined from the 1,200-foot level of the Eagle and Blue Bell mines, Tintic district.

Lead oxychlorite (unnamed).—An unnamed lead oxychlorite that has been determined in ore from the 1,000-foot level of the Eureka Hill mine, Tintic district, occurs as minute yellow orthorhombic (?) prisms and rounded aggregates.

OXIDES.

Quartz.—Quartz, SiO_2 (oxygen, 53.3 per cent; silicon, 46.7 per cent), occurs in many forms, being an important constituent of both the igneous and sedimentary rocks of the State and being perhaps the most universal and abundant gangue mineral of the ore deposits. It varies from the coarsely crystalline variety of many of the ore deposits, as those of the Park City district, and especially of the O. K. mine in the Beaver Lake district, and the Cactus mine in the San Francisco district, to the fine cherty variety common in the gold veins in the volcanic rocks of the Tushar Range and the Gold Springs-State Line districts and in the lead-silver deposits of the San Francisco district, and the cherty replacement of limestone that occurs in the Tintic, Ophir, and other districts.

Chalcedony.—Chalcedony, cryptocrystalline silica, essentially identical with the cherty material described under quartz, also forms veinlets and spherulites in the Tintic district.

Opal.—Opal, an amorphous silica with variable amount of water, though not recognized in the ore deposits, is associated with lavas at numerous localities.

Bismite.—Bismite, Bi_2O_3, occurs in the Eagle and Blue Bell mines, Tintic district, where it forms yellow earthy crusts on ore.

Arsenobismite.—Arsenobismite, $2Bi_2O_3.As_2O_5.2H_2O$ or $4Bi_2O_3.3As_2O_5.5H_2O$, is described from the 600-foot level of the Mammoth mine, Tintic district.

Kermesite.—Kermesite, $2Sb_2S_3.Sb_2O_3$, is associated with stibnite in the Bay State workings, American Fork district. It forms minute tufts of red prismatic crystals and probably accounts for the red staining along the stibnite seams.

Molybdite.—Molybdite, MoO_3, was noted from a prospect near the Jumbo vein, Gold Springs district, where it is evidently a secondary mineral.

Cuprite.—Cuprite, cuprous oxide, Cu_2O (oxygen, 11.2 per cent; copper, 88.8 per cent), is especially abundant in the oxidized copper ores of the Copper Mountain mine, Lucin district, of the Dixie mine, Tutsagubet district, and of the Imperial mine, San Francisco district, and is present elsewhere.

Tenorite or melaconite.—Tenorite, cupric oxide, CuO, is associated in the Brooklyn mine of the Tintic district with the new mineral crandallite. The cuprite of the Copper Mountain mine is surrounded by a thin layer of a black mineral, probably tenorite or melaconite, that has apparently resulted from the alteration of the cuprite.

Melaconite.—Melaconite, CuO, a black earthy mineral containing copper as its only metallic constituent, occurs as an alteration product of cuprite in the Copper Mountain mine, Lucin district, and in the Imperial mine, San Francisco district. This is melaconite or some allied mineral.

Periclase.—Periclase, MgO, occurs in contact-metamorphosed limestone in the Little Cottonwood district. It commonly forms the center of spherical bodies of brucite which have resulted from its alteration.

Massicot.—Massicot, lead monoxide, PbO, occurs as an alteration product of galena in the Park City district.

Hematite.—Hematite, iron sesquioxide, Fe_2O_3 (oxygen, 30 per cent; iron, 70 per cent), is an important constituent of the iron deposits of Iron County and is the principal mineral in the iron deposits of the Uinta Range. It is present in contact zones in several districts, being especially abundant in the Clifton, San Francisco, and Beaver Lake districts, as well as in Iron County. The well-crystallized variety, specularite, is abundant in the Cactus mine, San Francisco district, where it occurs in replacement deposits in quartz monzonite; and it is associated with pyrite and chalcopyrite in quartz veins of the Farmington district. Micaceous hematite with quartz forms a few prominent beds in the Algonkian rocks north of Ogden.

Ilmenite.—Ilmenite, titanic iron ore, $FeTiO_3$ (oxygen, 31.6 per cent; titanium, 31.6 per cent; iron, 36.8 per cent), occurs in the Colorado and Green river placers and in most of the igneous rocks of the State.

Spinel.—Spinel, $MgAl_2O_4$ (aluminum, 71.8 per cent; magnesia, 28.2 per cent), occurs in the Tintic, Park City, and Cottonwood districts as a contact mineral.

Brucite.—Brucite, $MgO.H_2O$, occurs in magnesian limestone near the contact with the granodiorite east of Alta; it appears to have been formed by the alteration of periclase.

Magnetite.—Magnetite, Fe_3O_4 (oxygen, 27.6 per cent; iron, 72.4 per cent), is an important constituent in the iron deposits of Iron County, where it occurs as a contact mineral and in veins in intrusive rock. It is also especially abundant in the Rocky, Little Cottonwood, and Clifton districts, and forms bodies of considerable size remote from exposed igneous contacts in the Willard district. It is present in small amount in practically all of the igneous rocks of the State and is abundant in the placer deposits of the Colorado and Green rivers.

Chromite.—Chromite, $FeCr_2O_4$, occurs in the Colorado and Green river placers.

Minium.—Minium, lead oxide, Pb_3O_4, has been recognized in the oxidized ores of the Park City and Tintic districts as a bright-red earthy coating.

Bixbyite.—Bixbyite, $FeO.MnO_2$, occurs with topaz in altered lava in the Thomas Range.

Rutile.—Rutile, TiO_2 (oxygen, 40 per cent; titanium, 60 per cent), occurs in the tourmaline veins of the Clifton district and of the Cactus mine of the San Francisco district, in the disseminated copper deposits of the Bingham district, and doubtless in small amounts in many other localities.

Octahedrite.—Octahedrite, TiO_2 (oxygen, 40 per cent; titanium, 60 per cent), occurs in the sericitic ore of the Deertrail mine, near Marysvale.

Diaspore.—Diaspore, $AlO(OH)$ (alumina, 85 per cent; water, 15 per cent), occurs in the altered lavas of the Beaver Lake Mountains.

Pyrolusite.—Pyrolusite, MnO_2, has been mined in the Little Grande district, where it occurs in sandstone, and similar occurrences are present in numerous localities through the Plateau region. It is present in considerable abundance in some of the deposits in the Little Cottonwood district, in prospects near Modena, in the Escalante mine and near-by prospects, in deposits in Bullion Canyon of the Tushar Range, in the iron deposits of the Antelope Range in Piute County, and at numerous other localities.

Manganite.—Manganite, $MnO(OH)$, occurs in the Horn Silver mine, San Francisco district, and probably in small amount in numerous localities.

Psilomelane.—Psilomelane, a hydrous manganese manganate, H_4MnO_5? (usually very impure), is common as black earthy masses or stains in oxidized ore bodies throughout the State.

Wad.—Wad, an impure black hydrous manganese oxide similar to psilomelane but usually soft and loosely aggregated, and psilomelane are present at some places, as in the Tintic district, in minable amounts.

Limonite.—Limonite, $2Fe_2O_3.3H_2O$ (oxygen, 25.7 per cent; iron, 59.8 per cent; water, 14.5 per cent), is present in practically all the ore deposits of the State and in many is very abundant. It has been mined as a flux from the Tintic and Lucin districts and from the Antelope Range, Piute County, and to a small extent from other localities.

Göthite.—Göthite, $FeO(OH)$, has been recognized in the gossan of the Cactus mine, San Francisco district.

"Copper pitch ore."—Hydrous oxides of copper, iron, and manganese, of variable com-

position, commonly termed "copper pitch," occur as oxidation products of copper ores, especially in the Imperial mine, San Francisco district, and in the Tintic district.

CARBONATES.

Calcite.—Calcite, calcium carbonate, $CaCO_3$, occurs in many forms. As limestone it makes up a large part of many of the mountain ranges of the State. As a gangue mineral it is present in many ore deposits, especially in replacement deposits in limestone and in the gold-silver veins in the volcanic rocks.

Dolomite.—Dolomite, carbonate of calcium and magnesium, $(CaMg)CO_3$, like calcite, is an important part of the sedimentary rocks in the mountains of the State, and is a common gangue mineral, especially in lead-silver and zinc ores.

Siderite.—Siderite, $FeCO_3$, an impure iron carbonate, is especially abundant in the Cactus mine, San Francisco district, but is also present in deposits of the Clifton district, the Tushar Range, and elsewhere.

Ankerite.—Ankerite, $(CaMgFe)CO_3$, resembles dolomite in appearance and mode of occurrence. It has been recognized in the Tintic district and is doubtless present elsewhere.

Rhodochrosite.—Rhodochrosite, $MgCO_3$, is not abundant, though much of the vein carbonate contains manganese in notable amount. Rhodochrosite occurs in the Dillon mine in the Tushar Range, is present in small amount in the Park City and Star districts, and doubtless occurs in small amounts at other localities.

Smithsonite.—Smithsonite, $ZnCO_3$ (zinc, 51.96 per cent), is present in many oxidized ore deposits of western Utah. It is everywhere secondary and very commonly replaces limestone or dolomite. It has been found in greatest abundance in the North Tintic, Tintic, Promontory, Ophir (Dry Canyon), and Star districts.

Hydrozincite.—Hydrozincite, basic zinc carbonate ($ZnCO_3.2ZnO_2H_2$?), occurs in the Tintic, Ophir, and Mount Nebo districts and probably elsewhere as chalk-white dense earthy masses and incrustations closely associated with smithsonite.

Aragonite.—Aragonite, calcium carbonate, $CaCO_3$, crystallizing in the orthorhombic system, has been noted in oxidized ore of the "1903" mine, West Tintic district, and in caves near ore bodies in the Tintic district. Aragonite containing a little zinc is associated with the oxidized zinc ores of the Gemini mine, Tintic district.

Cerusite.—Cerusite, lead carbonate, $PbCO_3$ (lead, 77.5 per cent), is the most important lead mineral in the oxidized ores of the State and is present in practically all deposits in which lead occurs, everywhere as an alteration product of galena or other lead minerals. Ordinarily the sulphide alters first to the lead sulphate, anglesite, and the sulphate to the carbonate.

Malachite.—Malachite, $CuCO_3.Cu(OH)_2$ (copper, 57.4 per cent), is present in the oxidized portion of practically all the copper deposits of the State.

Azurite.—Azurite, $2CuCO_3.Cu(OH)_2$ (copper, 55 per cent), like malachite, is present in the oxidized portion of practically all the copper deposits.

Aurichalcite.—Aurichalcite, $2(ZnCu)CO_3.3(ZnCu)(OH)_2$, has been noted in oxidized zinc ore from the Hidden Treasure mine in the Ophir district (Dry Canyon), in the Tintic district, from the Cave mine in the Mineral Range, and from the Carbonate mine, Big Cottonwood district.

Bismuthite.—Bismuthite, $Bi_2O_3.CO_2.H_2O$, occurs in the Boss Tweed mine and in the Victoria mine, Tintic district.

Leadhillite.—Leadhillite, $H_2Pb_4C_2SO_{12}$, hydrous sulphato-carbonate of lead, appears in the only specimen found (from the Eureka Hill mine, Tintic district) as white crystals associated with anglesite.

Phosgenite.—Phosgenite, $PbCl.CO_3$, has been found in the State only as gray crusts replacing the lead carbonate, cerusite.

SILICATES.

Orthoclase.—Orthoclase, $KAlSi_3O_8$, is an important constituent of most of the igneous rocks of the State. As a gangue mineral of ore deposits it occurs in the pegmatitic veins of the Park Valley district, in those of the Queen of Sheba mine, in the Deep Creek Range, and in the pegmatitic deposits of the Clifton district. It is present as adularia in the gold-silver veins in lavas of the Tushar and Gold Spring–State Line districts; it is an important alteration mineral of the quartz monzonite in the disseminated deposits of the Bingham district;

and it occurs as a replacement mineral in limestone in the Ophir district.

Plagioclase group.—The plagioclase group is an important constituent of most of the igneous rocks of the State. (End members of group: Albite, $NaAlSi_3O_8$, and anorthite, $CaAl_2Si_2O_8$; intermediate members are mixtures of these in different proportions.) Albite replaces limestone in the contact zones in the Iron Springs district.

Pyroxene group.—Of the members of the pyroxene group, augite and hypersthene are constituents of many of the igneous rocks of the State. Enstatite, associated with spinel, is an abundant microscopic mineral in altered dolomite in the contact zone of the Tintic district. Diopside is present in the altered limestone of most of the contact zones. Wollastonite is the principal gangue mineral in some of the contact gold deposits of the Clifton district, and has been found in the Tintic district. Rhodonite is present in the Park City district as a gangue mineral but is nowhere abundant.

Amphibole group.—Members of the amphibole group, especially hornblende, are, like those of the pyroxene group, important constituents of many of the igneous rocks of the State. Tremolite is especially common in the metamorphic limestone in contact zones. Actinolite has the same general distribution and mode of occurrence as tremolite. Hornblende in small amount has been noted in metamorphic limestone of the West Tintic district. Amphibole is a constituent of some of the veins in the quartz monzonite of the Clifton district.

Beryl.—Beryl, $Gl_3Al_2(SiO_3)_6$, is reported from quartz veins in the Ibapah stock, Deep Creek Range.

Willemite.—Willemite, anhydrous zinc silicate, Zn_2SiO_4 (zinc, 58.5 per cent), occurs in specimens of oxidized zinc ore from the Cedar Talisman mine, Star district, Beaver County, presented to the Survey by Mr. W. H. Parker. The willemite appears as abundant short, stout, hexagonal crystals associated with smithsonite, calamine, pyromorphite, and hydrous oxide of iron. It is in part at least later than calamine and is unquestionably secondary.

Garnet group.—Garnet of different compositions has been formed by a replacement of calcareous rocks in most of the contact zones of the State. Most of it is a mixture of andradite (iron-calcium garnet), grossularite (calcium-alumina garnet), and pyrope (magnesium-aluminum garnet), the andradite portion predominating. In the Little Cottonwood district a green chrome garnet (uvarovite) occurs in the contact zone. Garnet occurs in tourmaline veins in the quartz monzonite of the Clifton district and in the pegmatitic gold veins of the Queen of Sheba mine in the Deep Creek Range. It is present, commonly as the iron-aluminum variety, almandite, in many schists and gneisses. Garnet is a rather abundant constituent of the Colorado and Green river placers.

Vesuvianite.—Vesuvianite, basic calcium-aluminum silicate, has been recognized as a replacement mineral in the contact zones of the Park City, Little Cottonwood, and San Francisco districts and in the Mineral Range. It occurs in the tourmaline veins in quartz monzonite in the Clifton district.

Zircon.—Zircon, $ZrSiO_4$, is present in small amount in many of the igneous rocks of the State. It is rather abundant in the sericitic ores of the Deertrail mine and is present in the placers of Colorado and Green rivers.

Danburite.—Danburite, $CaB_2(SiO_4)_2$, occurs in the tourmaline veins of the Clifton district.

Topaz.—Topaz, $(AlF)_2SiO_4$, occurs in altered volcanic rocks in the Thomas Range.

Andalusite.—Andalusite, Al_2SiO_5, occurs in hydrothermally altered volcanic rocks of the Beaver Lake Mountains.

Monticellite.—Monticellite, $CaMgSiO_4$, forms microscopic crystals in the contact-metamorphosed limestone of the Cottonwood-American Fork region.

Zoisite.—Zoisite, $Ca_2(AlOH)Al_2(SiO_4)_3$, has been recognized as an alteration product of limestone in the contact zone in the Little Cottonwood district and in inclusions in monzonite of the Tintic district, and it is probably present at other localities.

Epidote.—Epidote, $HCa_2(Al,Fe)_3Si_3O_{13}$, is a common alteration product of limestone in the contact zones, as in the Iron King mine, West Tintic district. It is also produced by the hydrothermal alteration of limestones that are not closely associated with igneous rocks, notably in the deposits of the Ophir district. It occurs in the tourmaline veins of the Clifton district.

Axinite.—Axinite, boro-silicate of aluminum and calcium with varying amounts of iron and manganese, occurs as a replacement of limestone in the contact deposits of the Clifton district.

Calamine.—Calamine, H_2ZnSiO_5 (zinc, 54.2 per cent), is present in small or considerable amounts in the oxidized zinc ores of the State, but nowhere predominates in oxidized zinc ores. It has been noted in the Star, San Francisco, North Tintic, Tintic, and Mount Nebo districts and is present in small amounts at several other localities.

Tourmaline.—Tourmaline, complex silicate of boron and aluminum with magnesium, iron, or alkali metals, occurs in the Clifton district in pegmatite dikes, in veins in quartz monzonite, and in contact deposits. It is abundant in the Cactus mine, San Francisco district, in replacement veins in quartz monzonite.

Laumontite.—Laumontite, $H_4CaAl_2Si_4O_{14}$, occurs in a gold-copper vein in quartz monzonite in the Bromide mine in the Henry Mountains.

Heulandite.—Heulandite, $H_4CaAl_2(SiO_3)_6 + 3H_2O$, occurs in small gray to yellowish crystal aggregates lining cavities in rhyolite in a north continuation of the Gemini ore zone, Tintic district.

Chabazite.—Chabazite, $(CaNa_2)Al_2Si_4O_{12}$, occurs in small amount in the contact zone of the Park City and Cottonwood districts.

Muscovite (white mica).—Muscovite, $H_2KAl_3(SiO_4)_3$, occurs as an original constituent of igneous rocks and as a replacement of limestone near the contact of igneous rocks. As a contact mineral it has been noted especially in the San Francisco, Clifton, and Little Cottonwood districts and in the Mineral Range but is present at other localities. The finely crystallized variety commonly known as sericite is abundant as a product of the alteration of igneous rocks by vein-forming solutions. Such alteration is important in the Bingham, Tintic, San Francisco, Beaver Lake, Clifton, and other districts. Sericite has also formed abundantly in replacement veins in limestone, most strikingly in the Deertrail mine near Marysvale, where it is the most important gangue mineral. It is also plentiful in places in the Park City, Little Cottonwood, Bingham, Stockton, Ophir, and Fish Springs districts.

Sericite. See Muscovite.

Biotite (black mica).—Biotite, $(H,K)_2(MgFe)_2(AlFe)_2(SiO_4)_3$, is a constituent of much of the igneous rock of the region. It is a product of the alteration of monzonitic rocks by ore solutions in the Bingham and Clifton districts. It occurs as a contact mineral in the Rocky district.

Phlogopite (magnesian mica).—Phlogopite, $(H,K,MgF)_3.Mg_3.Al(SiO_4)_3$, has been noted as a contact mineral in limestone in the Cottonwood districts and in the Rocky district.

Chlorite.—Chlorite, a variable compound of iron, magnesium, and aluminum silicate, is a common alteration product of the dark silicates of the igneous rocks. It occurs in the Park City, West Tintic, and Mineral Range contact zones, in the tourmaline veins of the Clifton district, in the altered latite adjacent to the Beaver-Carbonate vein in the San Francisco district, and in veins cutting shale in the western part of the Erickson district, Simpson Mountains.

Serpentine.—Serpentine, $H_4Mg_3Si_2O_9$, is a common alteration product of the magnesian silicates both of the igneous rocks and of the contact zones.

Talc.—Talc, $H_2Mg_3(SiO_3)_4$, probably occurs at numerous localities in the State, as in the contact zone of the Tintic district, but is not nearly so abundant as it is generally supposed to be. Most of the white materials commonly designated talc prove, on examination, to be some other substance, as sericite, alunite, kaolin, or some other hydrous aluminum silicate.

Kaolinite (kaolin).—Kaolin, $H_4Al_2Si_2O_9$, hydrous aluminum silicates, are of common occurrence. Most of them are of variable composition and probably few correspond to kaolinite. They are particularly abundant in the Copper Mountain mine in the Lucin district and in the Dragon iron mine in the Tintic district.

Leverrierite (racewinite).—A hydrous iron-aluminum silicate corresponding in general to leverrierite has been described by A. N. Winchell from the Highland Boy mine, Bingham district, and called racewinite.

Thaumasite.—Thaumasite, $CaSiO_3.CaCO_3.CaSO_4.15H_2O$, occurs in veinlets cutting the zone of contact minerals in the Old Hickory mine, Rocky district.

Chrysocolla. — Chrysocolla, $CuSiO_3 + 2H_2O$ (silica, 34.3 per cent; copper oxide, 45.2 per cent (copper, 36 per cent); water, 20.5 per cent), is commonly present in oxidized copper ores. It is especially abundant in the Copper Mountain mine, Lucin district, and is present in considerable amount in the San Francisco, Tintic, West Tintic, and other districts.

Titanite.—Titanite, $CaTiSiO_5$, is a common minor constituent of the intrusive rocks of the State and occurs as microscopic crystals in the tourmaline veins of the Clifton district and in the contact zones of the West Tintic district.

PHOSPHATES, ARSENATES, AND VANADATES.

Apatite.—Apatite, $(CaF,O)Ca_4(PO_4)_3$, is a common minor constituent of the igneous rocks of the State and is rather abundant in the tourmaline veins of the Clifton district.

Pyromorphite. — Pyromorphite, $(PbO)Pb_4(PO_4)_3$, is of rather rare occurrence in the State but has been found in the Park City district; in the Escalante mine, of Iron County; in the Cedar Talisman mine, of the Star district; and in the Eureka Hill mine, of the Tintic district.

Crandallite.—Crandallite, hydrous phosphate of calcium and aluminum, has been found as light gray to yellowish or brownish, fibrous to dense crusts, lining cavities in quartz-barite-sulphide vein matter at the Brooklyn mine, Tintic district.

Borickite.—Borickite, hydrous basic phosphate of iron and calcium, has been reported to occur in the Ajax mine in reddish-brown massive form.

Mimetite.—Mimetite, $(PbCl)Pb_4(AsO_4)_3$, occurs in the oxidized ores of the Park City district and occurs rarely in the Tintic district.

Vanadinite.—Vanadinite, $(PbO)Pb_4(VO_4)_3$, occurs in the oxidized lead ores of the Harrington-Hickory mine, Star district.

Adamite.—Adamite, $Zn_3As_2O_8.Zn(OH)_2$, has been found with limonite in the Iron Blossom mine (No. 3 shaft), Tintic district.

Chenevixite.—Chenevixite, $Cu_2(FeO)_2As_2O_8 + 3H_2O$ (?), was obtained from the American Eagle mine, Tintic district, as a massive greenish-yellow mineral, not easily distinguished from massive varieties of olivenite.

Conichalcite.—Conichalcite, $(Cu, Ca)_3As_2O_8.CuCa(OH)_2 + \frac{1}{2}H_2O$ (?), probably the most widely distributed copper arsenate in the Tintic district, occurs as small, bright, yellowish-green fibrous spheres or more rarely as mammillary crusts; also present in the Gold Hill mine, Clifton district.

Erinite.—Erinite, $Cu_3As_2O_8.2Cu(OH)_2$, is a rather common arsenate in the Tintic district, forming small dark-green or dirty grayish-green mammillary crusts and fibrous spheres.

Chalcophyllite and tyrolite.—Chalcophyllite, $(Cu_3As_2O_8.2Cu(OH)_2 + 14H_2O$ (?)) and tyrolite $(Cu_3As_2O_8.2Cu(OH)_2 + 7H_2O$ (?)) are found rather commonly in the oxidized copper ores of the Tintic district, particularly in the Ajax and Mammoth mines. They form foliated and fan-shaped aggregates and are not readily distinguished except by optical means (chalcophyllite is uniaxial).

Olivenite.—Olivenite, $Cu_2(OH)AsO_4$, occurs in the Tintic district as an oxidation product of enargite; also in the Clifton district.

Descloizite.—Descloizite, $(PbZn)_2(OH)VO_4$, occurs as a coating of cavities in the ores of the Escalante mine.

Clinoclasite.—Clinoclasite, $Cu_3As_2O_8.3Cu(OH)_2$, occurs in the Tintic district as an alteration product of enargite.

Annabergite.—Annabergite, $Ni_3As_2O_8 + 8H_2O$, occurs in the ores of the Escalante mine.

Scorodite.—Scorodite, $FeAsO_4 + 2H_2O$, occurs as an oxidation product of arsenic minerals in several districts, including the Tintic, West Tintic, Star, Mercur, and Clifton. It is especially abundant in the Gold Hill mine of the Clifton district.

Variscite.—Variscite, $AlPO_4 + 2H_2O$, occurs about 5 miles northwest of Lucin, where it has been mined to some extent as a gem material.

Volborthite.—Volborthite, hydrous vanadate of copper barium and calcium, occurs in the ores of the Silver Reef and other sandstone deposits of the Plateau region.

Pharmacosiderite.—Pharmacosiderite, $6FeAsO_4.2Fe(OH)_3 + 12H_2O$, occurs in the Tintic and West Tintic districts.

Pintadoite.—Pintadoite, hydrous calcium vanadate, $2CaO.V_2O_5 + 9H_2O$, occurs as an efflorescence on the surface of vanadium-bearing sandstones of the Plateau region from Pintado Canyon, near the La Sal Mountains.

Uvanite.—Uvanite, hydrous uranium vanadate, $2UO_3.3V_2O_5 + 15H_2O$, occurs at Temple Rock on the east side of San Rafael Swell.

Carnotite.—Carnotite, $K_2O.2VO_3.V_2O_5+3H_2O$, occurs at numerous localities in the Plateau region, and is especially abundant around the La Sal and Henry mountains and the San Rafael Swell.

Tyuyamunite.—Tyuyamunite, $CaO.2VO_3.V_2O_5+H_2O$, occurs in Browns Park, Uinta Mountains.

Autunite.—Autunite, $Ca(UO_2)_2P_2O_8+8H_2O$, is reported from the ores of the Silver Reef, from "sandstone" deposits 9 miles south of Pahreah, and is probably present in other uranium deposits of the Plateau region.

Uranospinite.—Uranospinite, $Ca(UO_2)_2.As_2.O_8+8H_2O$, is reported from 9 miles south of Pahreah, Kane County.

Zeunerite. — Zeunerite, $Cu(UO_2)_2.As_2.O_8+H_2O$, has been found occasionally as small, yellowish-green tabular crystals on barite in the ore of the Centennial Eureka mine, Tintic district.

Mixite.—Mixite, hydrous basic arsenate of copper and bismuth, occurs in the ores of the Tintic district.

Bindheimite.—Bindheimite, hydrous antimonate of lead, occurs in the ores of the Park City and West Tintic districts and in the Horn Silver mine, San Francisco district.

Beudantite.—Beudantite, arsenate with sulphate of ferric iron and lead, occurs as an oxidation product in lead ores in the Clifton district.

Corkite.—Corkite, phosphate with sulphate of ferric iron and lead, occurs as an oxidation mineral in the Harrington-Hickory and Wild Bill mines, Star district.

BORATES.

Ludwigite.—Ludwigite, $3MgO.B_2O_3+FeO.Fe_2O_3$, occurs as a replacement of calcareous rocks in the Little Cottonwood district.

Magnesoludwigite.—Magnesoludwigite, $3MgO.B_2O_3+MgO.Fe_2O_3$, described from the Mountain View mine, at the head of Big Cottonwood Canyon. Replaces limestone the same as ludwigite.

SULPHATES.

Barite.—Barite, barium sulphate, $BaSO_4$, as a gangue mineral is especially abundant in the Tintic district and in the Horn Silver mine of the San Francisco district and is present in the Mineral Range, Tushar Range, Mercur, Ophir, Park City, American Fork, and other districts.

Anglesite.—Anglesite, lead sulphate, $PbSO_4$ (lead, 68.3 per cent) is the usual alteration product of galena, though it in turn is commonly altered to the carbonate, cerusite, which is more abundant in the oxidized ores than the sulphate. Anglesite is very abundant in the oxidized ores of the Horn Silver mine and is present in most, if not all, of the lead deposits of the State.

Anhydrite.—Anhydrite, anhydrous calcium sulphate, $CaSO_4$, occurs as a gangue mineral in the deposits of the Cactus mine, San Francisco district, and in some of the gypsum beds in the "red beds" of the Plateau region.

Celestite.—Celestite, strontium sulphate, $SrSO_4$, is associated with galena and zinc blende in Eocene sandstone, Salina Creek district.

Brochantite.—Brochantite, basic sulphate of copper, $CuSO_4.3Cu(OH)_2$, is rather abundant in the oxidized copper ores of the Horn Silver mine and is present in ores of the Tintic district and probably other districts.

Connellite and spangolite.—Connellite, basic hydrous chlorosulphite of copper, and spangolite, basic hydrous chlorosulphite of copper and aluminum, have recently been described from the Grand Central mine, Tintic district. Connellite forms bright Prussian-blue fibrous radiating crystals of almost metallic luster; spangolite forms hexagonal thick prisms, pale green to bluish green, with perfect basal cleavage.

Linarite.—Linarite, basic sulphate of lead and copper, $(Pb,Cu)SO_4(Pb,Cu)(OH)_2$, occurs in the oxidized ores of the Horn Silver mine, San Francisco district, and has been reported from the Bullion Beck or the Gemini mine and from the Mammoth mine, Tintic district.

Gypsum.—Gypsum, hydrous calcium sulphate, $CaSO_4+2H_2O$, is present in most of the districts and is rather abundant in the San Francisco district. It occurs in large amounts in the "red beds" of the Plateau region.

Goslarite.—Goslarite, hydrous zinc sulphate, $ZnSO_4+7H_2O$, is abundant as an efflorescence on the walls of old workings in the Horn Silver mine, San Francisco district, and is present in small amounts in other districts.

Melanterite.—Melanterite, hydrous ferrous sulphate, $FeSO_4+7H_2O$, has been recognized in the oxidized ores of the Mercur and Tintic districts and is doubtless present in other deposits.

Chalcanthite.—Chalcanthite, hydrous copper sulphate, $CuSO_4.5H_2O$, is a common efflorescence on the walls of old copper workings. It is especially abundant in the Horn Silver mine, San Francisco district, and the O K mine, Beaver Lake district, but it is present in many other mines.

Lettsomite (*cyanotrichite*).—Lettsomite, $4CuO.Al_2O_3.SO_3.8H_2O$, occurs in the Ajax, formerly the Copperopolis or American Eagle mine, Tintic district.

Utahite.—Utahite, $3Fe_2O_3.2SO_3.7H_2O$, has been described from the oxidized ores of the Tintic district It may be identical with jarosite, which is abundant in the Tintic ores.

Alunite.—Alunite, hydrous sulphate of aluminum and potassium, $K_2O.3Al_2O_3.4SO_3.6H_2O$, occurs in veins in the Tushar Range and is a rare microscopic vein mineral in the Tintic and Erickson districts. It is an alteration product of igneous rocks in mineralized areas of the Tushar Range and Tintic district. In the Horn Silver mine, San Francisco district, and in the Tintic district it has formed during the oxidation of the ores.

Jarosite.—Jarosite, $K_2O.3Fe_2O_3.4SO_3.6H_2O$, has been recognized in the Mercur, Tintic, Detroit, Star, San Francisco, Tutsagubet, and Argenta districts, in the Deertrail mine, near Marysvale, and at several localities in the Plateau region, and is probably present in other localities. It invariably occurs as a product of oxidation of sulphides.

Plumbojarosite.—Plumbojarosite, $PbO.3Fe_2O_3.4SO_3.6H_2O$, is rather common as an oxidation product in the oxidized lead ores of Utah. It has been recognized in the Star, San Francisco, Tutsagubet, Tintic, Ophir, Stockton, Lucin, Fish Springs, Clifton, Big Cottonwood, Little Cottonwood, and American Fork districts. In several mines it is a valuable ore mineral.

Beaverite.—Beaverite, $CuO.PbO.Fe_2O_3.2SO_3.4H_2O$, like the other basic ferric sulphates, is a product of the oxidation of sulphide ores. It was first described from the Horn Silver mine, San Francisco district. Material containing the same constituents and possibly identical with beaverite occurs in the Little Cottonwood and Ophir districts.

TUNGSTATES AND MOLYBDATES.

Scheelite.—Scheelite, calcium tungstate, $CaWO_4$ (tungsten trioxide, 80.6 per cent; calcium oxide 19.4 per cent), occurs in veins in quartz monzonite in the Clifton district; it also occurs 15 miles northeast of Lucin, as a contact deposit in limestone associated with the Grouse Creek stock.

Cuproscheelite.—Cuproscheelite is reported by F. L. Hess from the Clifton district.

Powellite.—Powellite, calcium molybdate, $CaMoO_4$, occurs as an oxidation product of molybdate in the Clifton and Beaver Lake districts.

Stolzite.—Stolzite, lead tungstate, $PbWO_4$, occurs in replacement veins in limestone in the Clifton district.

Wulfenite.—Wulfenite, lead molybdate, $PbMoO_4$, occurs as an oxidation product in the Lucin district, especially in the Tecoma mine, in several mines in the Little Cottonwood and American Fork districts, in the Harrington-Hickory mine, Star district, and in the Horn Silver mine, San Francisco district.

HISTORY AND PRODUCTION.

By V. C. Heikes.

CIVIL HISTORY.

The early history of the mining industry of Utah is closely bound up in that of the exploration and settlement of the region, an outline of which, prepared by Henry Gannett,[1] is in large part quoted below:

> The Territory of Utah was organized September 9, 1850, its area being a part of that acquired from Mexico by the United States in 1848. As originally organized, it extended from the summit of the Rocky Mountains in central Colorado westward to the east boundary of California, including all the territory between the parallels of 37° and 42° north latitude.
>
> The organization of Colorado Territory in 1861 reduced it on the east to its present eastern boundary, and the formation of the Territory of Nevada in the same year reduced it on the west to the meridian of 39° west of Washington. The enabling act of the State of Nevada, passed in 1864, moved the west boundary of Utah a degree farther east, placing it upon the meridian of 38°, and upon the admission of Nevada as a State in 1866 Utah was still further diminished and Nevada increased, the eastern boundary of the latter being placed upon the meridian of 37° west of Washington. Meantime, in 1863, the northeast corner of the State was cut off and added to the Territory of Idaho, and in 1866 a square degree in the northeast was added to the Territory of Wyoming, thus reducing Utah to its present dimensions. [See fig. 11.] On January 4, 1896, it was admitted as a State.
>
> The area of the State is 84,970 square miles, of which it is estimated that 2,780 square miles are water surface, including Great Salt, Utah, and other lakes, and 82,190 square miles are land surface.

[1] Gannett, Henry, A gazetteer of Utah: U. S. Geol. Survey Bull. 166, 1900.

From a very early time this region was traversed by Spanish caravans, traveling from Santa Fe, N. Mex., to Los Angeles, Cal. The old Spanish trail, which these caravans followed, entered Utah on the east near Dolores River, crossed the Grand near the Sierra La Sal, and the Green at the present crossing of the Rio Grande Western Railway. It reached the valley of Sevier River near its bend, and turning south followed its valley to the head and down the Virgin to a point near its southwest corner. This traffic, which at one time was great, left, however, no trace behind in the form of a settlement, and it was not until the hegira of the Mormons from the Mississippi Valley in 1847 that the present State of Utah received any permanent inhabitants.

The earliest recorded exploration of any part of Utah was a journey by two Franciscan fathers, Escalante and Dominguez, from Santa Fe, N. Mex., to the shores of Great Salt Lake, in 1776–77. So far as can be learned, their route followed in the main that of the old Spanish trail, and it is not at all improbable that they were the pioneers in laying out the western part of this route to southern California. So far as known, they were the first white men to visit the eastern part of the Great Basin of Utah. This

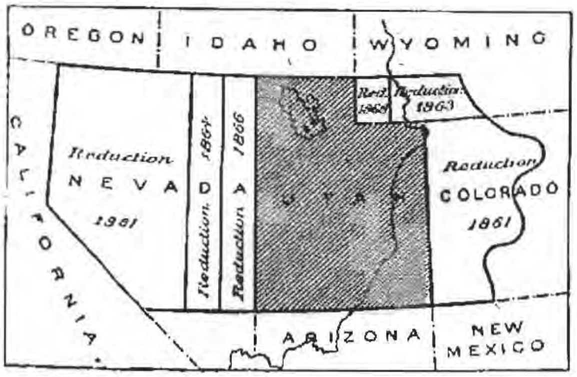


FIGURE 11.—Map of Utah showing changes of boundary.

journey was not, however, fruitful in geographical discovery, excepting the fact that it may have determined the route of travel between the Spanish settlements of New Mexico and those of California.

Between 1832 and 1836 Capt. B. L. E. Bonneville, of the United States Army, while on leave of absence, engaged in the fur trade in the West and coupled with it a certain amount of exploration. He traveled extensively over the northeastern part of Utah, including the area drained by Bear River and its tributaries, and sent a branch expedition, under Capt. Walker, to Great Salt Lake, down Humboldt River, and across the Sierra Nevada to California, returning by the route of the Spanish trail. No maps were prepared, and the only information derived from these explorations is contained in Washington Irving's narrative, which is very scanty and often erroneous.

The real exploration of Utah began in 1842, when Capt. J. C. Frémont, with an army expedition, entering the region via Bear River, explored Great Salt Lake and the adjacent region. Upon his return from California in the following year he entered the Territory again, on the south, via Virgin River and the Sevier, reaching Utah Lake, and thence proceeded northeastward down Uinta River.

Subsequent expeditions under army auspices, notably those of the Pacific Railroad explorations, Capt. Stansbury's survey of Great Salt Lake, and Capt. Simpson's explorations, made the main features of the Territory well known.

Green and Colorado rivers, which flow mainly within this State, were explored by a daring boat journey undertaken and carried through by J. W. Powell in 1869, and in the course of this exploration the greater features of the plateau region traversed by the rivers were delineated and their structure was explained.

The explorations of the geologists of the Fortieth Parallel Survey, Messrs. King, Hague, and Emmons, of the Wheeler and Hayden surveys, and later of the United States Geological Survey, carried on mainly by Messrs. Powell, Gilbert, Walcott, Marvine, Howell, Holmes, Peale, and Dutton, early gave a general knowledge of the geography and geology of the State, which has later been studied in greater detail in many areas by members of the United States Geological Survey and others.

Although the early explorations of the area date back to the time of the Declaration of Independence, 1776, no permanent settlement of white people was made till 1847. On July 24 of that year a company of Mormons, under the leadership of Brigham Young, arrived in the valley of Great Salt Lake and formed a settlement on the site of Salt Lake City. The first pioneers were quickly followed by many of their fellows who had been driven from their homes in the Mississippi Valley, so that by 1850 the Territory had a population of 11,380 people. Under the direction of the Mormon Church colonization was rapid, and 25 years after the arrival of the first immigrants at Salt Lake settlements had been established on nearly all the important streams where irrigation was practicable or where conditions were especially favorable to stock raising.

The rapid increase of population of the State is shown in the following table:

Population of Utah at the census years since 1850.

Year.	Population.	Per cent of increase.
1850	11,380	....
1860	40,273	254
1870	86,786	116
1880	143,963	66
1890	207,905	45
1900	276,749	33
1910	373,351	35

MINING HISTORY.

In contrast with many of the Cordilleran States the rancher preceded the prospector, and many agricultural communities were well established before mining became of any importance. Several factors doubtless contributed to this order of development. The leaders of the Mormon Church for several years discouraged prospecting; the rich and extensive placer deposits that were the first incentive to mining in many western camps were lacking; and the lode deposits, though many of them were very rich, required extensive machinery for profitable exploitation.

That the settlers were aware of the presence of metalliferous deposits in the mountains is shown by the fact that in the fifties some lead ore was crudely reduced to bullion for use as bullets. In 1859 a Government report[1] mentions the existence of a rich mine of lead ore in Washington County, near the Vagas (now Las Vegas, Nev.) According to the records[2] of the Las Vegas Mormon Mission four members who were taken to this mine by a Piute Indian guide on April 21, 1856, returned two days later with 180 pounds of the ore and reported that they had procured it 35 miles southwest of Las Vegas. In December, 1856, some of this ore was reduced to metal.

Isaac Grundy, who is credited with[3] building a lead furnace (the first west of the Rocky Mountains) in the Lincoln district, was, according to the records of the Mormon Church, a Virginian who came to Salt Lake City in 1847, and years later was called upon by Brigham Young to develop the lead mines near the place later called Minersville. The first metal produced in the State is said to have been from the Rollins or Lincoln mine in this district.

An event of great importance in the mining industry of Utah was the arrival in October, 1862, of Gen. E. P. Conner, with his California volunteers, who established themselves at Camp Douglas, overlooking Salt Lake City.

Parties of these soldiers, most of whom were prospectors, began searching the mountains for metals. Whether Gen. Conner deliberately encouraged prospecting with the hope of causing an influx of gentile population, as the Mormon leaders are reported to have discouraged it to prevent such an influx, may be doubted. His men, many of whom had seen the gold excitement of California, doubtless needed little encouragement.

The year following the coming of the California soldiers metalliferous deposits were located in the ranges in the vicinity of Salt Lake; on September 17, 1863, the first mineral location in Utah (the West Jordan claim) was made in Bingham Canyon; and in December the first mining district (the West Jordan) was formed. After this, discoveries and locations were made rapidly. In 1865 the production of gold from the placers in Bingham Canyon began, but it was not till 1870 that production from the lead-silver deposits of the State became important. Since that time, except for a few depressions, increase in the metal output has been steady.

RAILROAD CONSTRUCTION.

GENERAL FEATURES.

In 1849–50 Capt. Stansbury was detailed by the Government to find a route for a transcontinental railroad; and in 1853 Lieut. Gunnison was detailed to survey a route south of the Uinta Mountains through central Utah to California but was killed by the Indians in Utah. The Union Pacific was completed to Ogden in 1869 and the Utah Central to Salt Lake in 1870.

On the advent of these railroads metal production became important, and as each branch line was completed a notable increase in output was observed. Several smelting towns, Sandy, Midvale (Bingham Junction), Murray (Germania), and Morgan, were built along the new lines south of Salt Lake, and several smelters along the branch line to Bingham. The road from Sandy to Alta was also beneficial, and as the railroad extended southward other mining regions were benefited, notably Tintic and several districts in Beaver County.

The principal railroad systems operating in Utah to-day are the Union Pacific (Oregon Short Line and Southern Pacific), the Denver & Rio Grande, the Western Pacific, and the Los Angeles & Salt Lake.

[1] Explorations across the Great Basin of Utah; contains letter dated March 26, 1859, concerning the resources of Utah, from Dr. Garland Hurt, of Salt Lake City, to Capt. J. H. Simpson, at Camp Floyd.

[2] Historian's Office, Mormon Church, Salt Lake City.

[3] Eissler, Manuel, Metallurgy of argentiferous lead, preface, 1891.

UNION PACIFIC SYSTEM.

The first line built was the Union Pacific Railroad, which reached Ogden on March 3, 1869, and Promontory on May 10, 1869, completing the first transcontinental railway by connecting there with the Central Pacific Railroad. In 1904 the Southern Pacific Ogden-Lucin cut-off, with an easier grade and less mileage, was built farther south across the Great Salt Lake, and now handles most of the traffic, though trains are still operated over the old line and serve the Park Valley district in Box Elder County and the northern end of Promontory district.

The Utah Central Railroad Co. started construction from Ogden May 17, 1869, a week after the completion of the transcontinental route, and completed the 37 miles to Salt Lake City on January 10, 1870. In 1881 it was consolidated with the Utah Southern. In 1890 the Utah & Nevada, Utah & Northern, Salt Lake & Western, Oregon Short Line, and Echo & Park City railroads were united under the management of the Union Pacific as the Oregon Short Line and the Utah & Northern railroads. Later, the line north of Salt Lake was taken over by the Oregon Short Line, and all the lines south of Salt Lake (including the Utah Central) not owned by the Denver & Rio Grande by the Los Angeles & Salt Lake Railroad.

The Echo & Park City Railroad was completed from Echo to Park City in December, 1880, as a broadgage branch of the Union Pacific. It soon replaced two other roads, the Summit County Railroad from Echo to Coalville and the Utah Eastern Railroad from Coalville to Park City.

The Utah & Northern Railroad was organized August 23, 1871, and was completed from Brigham to Logan in Cache County January 1, 1873, and to Franklin, Idaho, in May, 1874. It connected with the Central Pacific at Brigham and also at Corinne, 4 miles farther west. On February 8, 1874, the road was extended to Ogden and operated independently till February, 1877, when it was purchased by the Union Pacific Railroad, made broadgage, and, in 1890, absorbed by the Oregon Short Line system.

DENVER & RIO GRANDE SYSTEM.

The Denver & Rio Grande Railroad began construction in Colorado. Its line in Utah was the Rio Grande Western, a narrow-gage road begun in 1881, completed in May, 1883, and widened to standard gage in May, 1890. In June, 1890, the company began the construction from Thistle Junction southward through San Pete and Sevier valleys of a branch line which it completed to Marysvale, its southern terminus, in 1900. In 1891 it built a branch line from Springville to Eureka and Mammoth in the Tintic district.

Other branches of the Rio Grande Western are the Alta branch (Wasatch & Jordan Valley Railroad), between Sandy and Wasatch; Bingham branch (Bingham Canyon & Camp Floyd Railroad), between Midvale and Bingham; Pleasant Valley branch, between Colton on the main line and Clear Creek; Park City branch, between Roper on the main line and Park City. The oldest of these branches is the Bingham Canyon & Camp Floyd, which was completed from Sandy to Bingham by December 1, 1874, was bought in 1883 by the Rio Grande Western, and was made standard gage in 1890. It now connects with the main line at Midvale (Bingham Junction).

The Wasatch & Jordan Valley Railroad was completed to Granite on May 3, 1873, to Fairfield Flat on September 28, 1873, and later to Alta. The road, about 8 miles of which was covered by snowsheds, was abandoned from Granite (now called Wasatch) to Alta in the eighties, but its lower part to Wasatch was later repaired and used to haul granite to Salt Lake City and ore from Wasatch. Tracks were laid on the old roadbed from Midvale to Wasatch in 1913–14. The line is now known as the Salt Lake & Alta Railroad. A narrow-gage line was completed from Wasatch to Alta in 1918.

The Utah & Pleasant Valley Railroad was commenced in 1876, and in 1883 became part of the main line of the Rio Grande Western.

The San Pete Valley Railroad, which extends from Nephi through Salt Creek Canyon to Morrison is now operated by the Denver & Rio Grande Railroad.

The Salt Lake & Eastern Railroad, now the Park City branch of the Denver & Rio Grande, was finished in 1890.

The Western Pacific Railroad, part of the Rio Grande system, was started in 1905 to connect Salt Lake City with San Francisco.

In 1917 a branch line of the Western Pacific was established from Wendover to Gold Hill in the Clifton district.

LOS ANGELES & SALT LAKE RAILROAD.

Early in 1905 the Los Angeles & Salt Lake Railroad was completed from Salt Lake to Los Angeles and San Pedro. The Ophir district is connected with the line at St. John by the St. John & Ophir branch.

The Utah Southern Railroad was begun at Salt Lake May 1, 1871, and had reached Provo by December, 1873, and Juab by June, 1879. From Juab the road was continued by the Utah Southern Railroad Extension Co. to Milford in May, 1880. The Horn Silver mine in the town of Frisco was reached June 23, 1880. Continuation of this branch to Newhouse, the present terminus, was completed in 1905. The line from Milford was continued to Modena and thence to the Pacific coast by the Los Angeles & Salt Lake Railroad.

In 1872 the Salt Lake, Sevier Valley & Pioche Railroad, afterward called the Utah Western and also the Utah & Nevada, a narrow-gage road designed to serve the mines and smelters at Stockton and Ophir, was begun and after some years was finished to Terminus, near Stockton. The road was subsequently purchased by the Union Pacific system and in 1905 made part of the broad-gage line of the Los Angeles & Salt Lake Railroad.

The Salt Lake & Western Railroad was built as a branch of the Union Pacific, which subsequently turned it over to the San Pedro, Los Angeles & Salt Lake Railway Co. It starts from Lehi, in Utah Valley, serving Fairfield, the junction of the abandoned line to Mercur. Short spurs were built to Mammoth and Silver City, and the line was completed to Eureka in 1883.

The Salt Lake & Mercur Railroad, a broad-gage line, was completed in 1895 and dismantled in 1914, a year after most operations at Mercur had ceased.

The American Fork Railroad, from the old Utah Central station on American Fork, to Deer Creek in American Fork Canyon, was completed in 1872 but was soon abandoned.

In 1907 the Eureka Hill Railway Co. built a narrow-gage railroad to connect various mines with the smelter and ore sampler at Silver City in the Tintic district.

The Bingham & Garfield Railroad, owned by the Utah Copper Co., was completed in 1911 to haul ore to the Garfield mill.

METALLURGIC DEVELOPMENT.

Utah has been the scene of many important advances in metallurgy, and an adequate treatment of the development of processes in use within her borders would require much study and a volume for its presentation. No serious attempt is therefore made in this paper to treat this phase of the mining industry systematically, though its commercial importance is commensurate with that of the development of the mines. Only the general changes in treatment are outlined and, in the history of the several districts, the general treatment of the ores at different stages is stated.

In the early days of the industry most of the metallurgic plants were at the mines or as near them as suitable supplies could be had. The plants consisted mainly of mills for the treatment of the silver ores and of crude smelters, which often failed, for the reduction of the oxidized lead ores. Later there was a marked tendency to concentrate the smelters in Salt Lake Valley and to bring the ores and fuel to them. This change was probably largely due to the greater efficiency of the larger plants, the advantages to be gained by mixing the ores of different districts, and the exhaustion of the fuel supply in many districts.

Still later, when the rich oxidized ores were exhausted, it became necessary to erect mills at or near the mines to concentrate the metallic constituents and in some ores to separate the different metallic minerals, which were then sent to the smelters for reduction. Such mills have been erected in the Park City, Bingham, and other districts. In recent years the development of the large bodies of low-grade copper ores of the Bingham district has resulted in the erection

of the great mills at Garfield, where more than 30,000 tons of ore can be daily concentrated, and the smaller mill at Lark. A mill was also constructed at Newhouse to treat the ore from the Cactus mine.

In the treatment of gold ores Utah was a pioneer in developing the cyanide process, which transformed the operations of the Mercur camp from a forlorn hope to an important commercial enterprise.

At present most of the ores and concentrates produced from the mines in Utah are treated at the four valley smelters, but the zinc ores, which in recent years have become of increasing importance, are still mostly shipped out of the State for final treatment, though electrolytic plants for producing zinc are in operation. Several mills for the treatment of gold ores are operated, and in the last few years processes have been developed for the treatment of ores that are chiefly valuable for their silver. It is expected that these processes will make it possible to rework much of the waste of earlier operations.

The relative importance of the different types of treatment are indicated in the following tables, which show the output of the mills by amalgamation and by cyanidation and of the smelters from crude ore and from concentrates for the period 1903–1916.

Tonnage of and recovery from ores handled by gold and silver mills by amalgamation and cyanidation, 1903–1917.

Year.	Quantity (short tons).	Gold.			Silver.			Total value.	Average recovery value per ton.
		Fine ounces.	Value.	Value per ton.	Fine ounces.	Value.	Ounces per ton.		
1903	445,114	84,651.00	$1,749,891	$3.93	124,046	$66,985	0.28	$1,816,876	$4.08
1904	363,883	57,773.00	1,194,274	3.28	72,493	42,046	.20	1,236,320	3.40
1905	416,530	64,117.00	1,325,416	3.18	80,713	49,235	.19	1,365,651	3.28
1906	408,712	61,365.60	1,268,540	3.10	52,994	36,036	.13	1,304,576	3.19
1907	263,020	41,507.06	858,027	3.26	42,049	27,752	.16	885,779	3.37
1908	313,845	45,968.09	950,245	3.03	18,662	9,891	.06	[a] 960,136	3.06
1909	287,659	39,861.43	824,009	2.86	5,153	2,680	.02	826,689	2.87
1910	263,041	36,480.92	754,127	2.87	4,612	2,490	.02	[b] 756,617	2.88
1911	267,111	30,312.22	626,609	2.35	112,493	59,621	.42	[c] 686,230	2.57
1912	171,117	21,288.69	440,076	2.57	64,468	39,648	.38	[d] 479,724	2.80
1913	75,972	13,117.41	271,161	3.57	61,032	36,863	.80	[e] 308,024	4.05
1914	2,166	739.33	15,282	7.06	11,536	6,379	5.33	[f] 21,706	10.02
1915	2,167	1,388.88	28,708	13.25	6,494	3,292	3.00	[g] 32,003	14.77
1916	1,423	309.09	6,389	4.49	340	224	.24	6,613	4.65
1917	190	140.66	2,908	15.31	26	21	.11	2,929	15.42

[a] Includes bullion from 32,773 tons of old tailings re-treated by cyanidation.
[b] Includes bullion from 34,751 tons of old tailings re-treated by cyanidation.
[c] Includes bullion from 4,600 tons of old tailings re-treated by cyanidation.
[d] Includes bullion from 250 tons of old tailings re-treated by amalgamation.
[e] Includes bullion from 7,125 tons of old tailings re-treated by cyanidation.
[f] Includes bullion from 15,500 tons of old tailings re-treated by cyanidation.
[g] Includes bullion from 46 tons of old tailings re-treated by amalgamation; and bullion from 11,250 tons of old tailings re-treated by cyanidation.

Crude ores produced in Utah and shipped to smelters, by kinds, 1903–1917.

Kinds of crude ore.	Quantity (short tons).	Gold.		Silver.		Copper.		Lead.		Recoverable zinc.		Total value.	Average gross value per ton.
		Fine ounces.	Value per ton.	Fine ounces.	Ounces per ton.	Pounds.	Per cent.	Pounds.	Per cent.	Pounds.	Per cent.		
Dry or siliceous:													
1903	67,463	35,784.75	$10.96	932,743	13.82	847,239	0.63	379,970	0.28			$1,375,448	$20.39
1904	53,036	25,129.00	9.79	770,900	14.53	221,648	.21	662,047	.62			1,023,423	19.30
1905	57,573	11,302.00	4.06	756,512	13.14	454,799	.39	1,445,004	1.25			833,968	14.48
1906	86,912	25,225.89	6.00	863,868	9.94	714,763	.41	1,169,687	.67			1,313,514	15.11
1907	37,002	25,865.93	14.45	337,376	9.12	120,527	.16	51,126	.07			784,179	21.19
1908	7,646	2,211.41	5.98	195,411	25.56	9,911	.06	69,580	.45			153,512	20.08
1909	21,101	9,110.84	8.92	397,922	18.86	299,031	.71	357,285	.85			449,494	21.30
1910	93,772	10,735.91	2.37	543,886	5.70	1,029,927	.55	522,889	.28			669,438	7.14
1911	189,424	48,567.32	5.30	2,451,673	12.94	3,256,340	.86	2,552,128	.67			2,825,253	14.91
1912	196,846	49,822.50	5.23	3,410,636	17.33	3,326,787	.84	1,763,257	.45			3,755,731	19.08
1913	127,253	19,559.62	3.17	1,769,019	13.90	1,447,177	.57	1,019,255	.40			1,741,981	13.69
1914	89,246	17,274.07	4.00	1,005,761	11.27	1,972,888	1.11	686,949	.38			1,202,458	13.47
1915	47,513	7,817.78	3.40	1,018,088	21.42	686,681	.72	1,010,054	1.06			845,419	17.79
1916	58,514	7,940.63	2.80	946,333	16.17	977,497	.84	246,028	.21			1,044,274	17.84
1917	97,786	18,846.31	3.98	1,834,547	18.76	1,760,377	.90	974,835	.50			2,465,674	25.21
Copper:[a]													
1903	517,882	70,020.91	2.79	2,291,016	4.42	26,622,504	2.57	750				6,331,924	12.23
1904	677,587	98,150.00	2.99	2,824,597	4.17	35,718,670	2.64	8,169				8,239,547	12.16
1905	821,154	144,427.00	3.64	3,554,064	4.33	40,763,987	2.48	87,815				11,516,860	14.02
1906	767,068	132,260.84	3.56	2,750,206	3.58	38,663,339	2.52	256,410	.02			12,080,853	15.75
1907	908,319	137,211.81	3.12	3,110,686	3.42	41,317,808	2.27	62,744				13,156,360	14.49
1908	644,488	93,245.58	2.99	2,282,903	3.54	29,987,867	2.33	1,195,285	.09			7,146,097	11.09
1909	753,278	93,454.82	2.56	2,257,839	3.00	35,315,285	2.34	1,547,324	.10			7,763,480	10.31
1910	568,845	72,713.33	2.64	1,654,963	2.91	30,116,632	2.65	221,127	.02			6,231,385	10.95
1911	640,729	73,160.10	2.36	1,926,406	3.01	32,637,950	2.55	338,688	.03			6,628,332	10.34
1912	572,354	68,251.32	2.46	2,187,869	3.82	25,000,452	2.18	2,194,024	.19			6,980,226	12.19
1913	662,892	70,385.88	3.19	1,988,922	3.00	25,719,652	1.94	147,344	.01			6,649,343	10.03
1914	471,626	62,091.43	2.72	1,367,744	2.90	17,209,706	1.82	2,179				4,328,883	9.18
1915	509,762	63,583.24	2.58	1,667,586	3.27	21,478,606	2.10	20,401	.02			5,919,566	11.61
1916	732,680	66,367.81	1.87	2,144,660	2.92	29,962,228	2.04	6,540	Trace.			10,154,290	13.86
1917	617,156	44,546.28	1.49	1,698,521	2.75	28,262,873	2.29	12,772	...do..			10,042,757	16.27
Lead:													
1903	150,862	15,502.48	2.12	6,965,581	46.17	3,233,847	1.07	73,420,251	24.33			7,608,566	50.43
1904	187,620	15,210.00	1.68	6,317,459	33.67	3,000,313	.80	86,263,622	22.99			8,071,921	43.02
1905	179,679	20,014.00	2.30	4,594,862	25.57	2,215,582	.62	77,411,488	21.54			7,200,563	40.07
1906	266,450	23,119.96	1.79	5,999,799	22.52	2,631,334	.49	87,927,835	16.50			10,077,530	37.82
1907	222,685	27,620.67	2.56	5,429,476	24.38	1,987,936	.45	81,052,354	18.20			8,847,786	39.73
1908	130,931	15,783.91	2.49	4,606,656	35.18	1,685,373	.64	62,423,595	23.84			5,612,070	42.86
1909	220,616	30,260.82	2.83	7,194,261	32.60	2,356,409	.53	101,915,747	23.10			9,055,273	41.04
1910	221,648	26,565.39	2.48	5,926,111	26.74	2,408,908	.54	69,645,351	15.71			7,119,581	32.12
1911	261,333	22,989.65	1.82	5,400,455	20.66	2,587,717	.50	84,244,320	16.12			7,451,938	28.51
1912	252,888	20,647.98	1.68	5,073,891	20.06	3,058,179	.60	83,074,776	16.42			7,790,239	30.80
1913	357,196	30,343.39	1.76	6,241,585	17.47	4,582,358	.64	107,078,919	14.99			9,818,909	27.49

1914	337,233	25,793.35	1.58	6,297,819	18.67	4,354,094	.65	113,444,741	16.82			9,019,330	26.74
1915	378,352	42,088.65	2.30	7,010,661	18.53	5,369,670	.71	133,180,077	17.63			11,623,611	30.72
1916	454,396	27,424.38	1.24	7,295,424	16.05	5,334,126	.59	134,905,027	14.84			15,987,943	35.18
1917	446,786	23,560.56	1.09	6,872,954	15.38	5,259,363	.59	121,166,005	13.56			18,006,437	40.30
Zinc:													
1904	522			1,649	3.16					332,924	31.89	17,935	34.36
1905	8,445	95.00	.23	18,108	2.14					5,130,220	30.37	315,693	37.38
1906	6,451			16,150	2.50					2,956,476	22.91	191,327	29.66
1907	12,251			33,059	2.70					5,194,132	21.20	328,273	26.79
1908	99	.99	.21	1,044	10.54			11,536	5.83	54,902	27.73	3,638	36.75
1909	3,264									1,817,542	27.84	98,147	30.07
1910	4,876	12.77	.05	5,941	1.21	1,005	.01	206,246	2.12	2,529,565	25.94	149,272	30.61
1911	1,316									877,876	33.35	50,039	38.02
1912	9,391	102.06	.22	14,631	1.55			624,785	3.33	5,596,442	29.80	425,378	45.30
1913	15,300			13,576	.89			871,435	2.85	9,416,157	30.77	573,847	37.51
1914	4,670									2,984,486	31.95	152,209	32.59
1915	17,210	.82		10,818	.63	1,250		272,737	.79	9,449,868	27.45	1,190,324	69.16
1916	16,889			2,914	.17			230,877	.68	8,467,927	25.07	1,152,550	68.24
1917	6,535							60,078	.46	3,664,962	28.04	378,993	57.99
Copper-lead:													
1903	2,129	113.44	1.10	38,328	18.00	531,133	12.47	693,275	16.28			124,924	58.68
1904	5,100	193.00	.78	28,668	5.62	1,386,179	13.59	1,677,931	16.45			270,200	52.98
1905	1,384	245.00	3.66	44,813	32.38	140,083	5.06	753,834	27.23			89,684	64.80
1906	6,183	293.02	.98	170,528	27.58	683,966	5.53	1,182,703	9.56			321,436	51.98
1907	8,510	783.06	1.90	307,432	36.12	818,897	4.81	1,189,932	6.99			445,938	52.40
1908	2,874	53.20	.38	62,569	21.77	265,152	4.61	794,114	13.82			102,614	35.70
1909	4,419	95.10	.44	98,127	22.20	528,155	5.98	1,422,266	16.09			182,809	41.27
1910	5,223	113.27	.45	157,296	30.12	404,959	3.88	3,845,108	36.81			307,896	58.95
1911	2,219	105.68	.98	72,849	32.83	278,772	6.28	728,046	16.41			108,404	48.85
1912	3,387	170.40	1.04	138,719	40.96	292,839	4.32	852,190	12.58			175,501	51.82
1913	2,740	68.57	.52	103,931	37.93	245,193	4.47	909,499	16.60			142,214	51.90
1914	1,077	65.42	1.26	33,941	31.51	90,083	4.18	234,425	10.86			41,245	38.30
1915	5,216	62.99	.25	70,836	13.58	349,692	3.34	905,896	8.67			140,989	27.03
1916	9,592	416.38	.89	144,753	15.09	556,622	2.90	1,686,061	8.79			357,122	37.23
1917	6,326	75.28	.25	91,447	14.46	385,688	3.05	1,414,923	11.18			303,884	48.04
Lead-zinc:													
1909	897	8.00	.18	8,122	9.05			231,827	12.92	656,457	36.59	49,807	55.52
1910	2,170	6.08	.05	845	.39	623	.01	432,463	9.96	878,117	20.23	67,106	30.92
1911	8,033	66.05	.17	8,282	1.03	4,092	.02	1,728,368	10.76	3,805,703	23.69	309,967	37.46
1912	1,402			613	.44			201,433	7.18	754,421	26.90	61,496	43.86
1913	569			33	.06			141,670	12.45	307,032	26.98	23,448	41.22
1914	6,246	3.06		16,196	2.51			1,060,762	8.21	4,119,160	31.89	260,466	40.34
1915	14			234	16.71			2,616	7.14	7,068	21.43	1,118	79.86
1916	9,505	1.23	Trace.	1,974	.21			1,554.100	8.18	2,967,432	15.61	506,194	53.25
1917	3,413	2,00	.01	660	.19			801,118	11.74	754,339	11.05	146,424	42.90

a Part of copper ore containing lead was treated at lead plants.

Concentrates produced in Utah and shipped to smelters, by kinds, 1903–1917.

Kinds of concentrates.	Quantity (short tons).	Gold.		Silver.		Copper.		Lead.		Recoverable zinc.		Total value.	Average gross value per ton.
		Fine ounces.	Value per ton.	Fine ounces.	Ounces per ton.	Pounds.	Per cent.	Pounds.	Per cent.	Pounds.	Per cent.		
Dry or siliceous:													
1904	885	850.00	$19.85	27,808	31.42	2,900	0.16					$34,071	$38.50
1905	15	32.00	44.07	1,132	75.47							1,351	90.07
1906	59	394.85	138.34	102	1.73							8,231	139.51
1907	10	17.83	36.80	772	77.20							878	87.80
1913	22	55.02	51.68	1,424	64.73							1,997	90.82
1914	62	67.00	22.34	1,638	26.42			3,680	2.97			2,434	39.26
1915	2	33.47	345.91	39	19.50			953	23.82			758	379.00
1916	1	.29	6.00	478	478.00							321	321.00
1917	120	5.61	.97	2,391	19.92	1,994	.83					2,630	21.92
Copper:													
1904	9,215	1,272.00	2.85	11,801	1.28	4,772,916	25.90					644,072	69.89
1905	32,266	3,458.00	2.22	51,101	1.58	11,784,938	18.26					1,941,312	60.16
1906	35,322	3,981.23	2.34	57,331	1.62	11,862,742	16.79					2,411,000	68.26
1907	51,224	6,990.96	2.82	87,760	1.71	18,518,093	18.08					3,906,056	76.25
1908	121,046	17,671.97	3.02	175,545	1.45	53,411,303	22.06					7,508,643	62.03
1909	147,976	23,699.63	3.31	230,552	1.56	68,173,413	23.04					9,472,346	64.01
1910	181,201	40,916.99	4.67	391,826	2.16	91,975,100	25.38					12,738,253	70.30
1911	228,591	42,589.23	3.85	431,405	1.89	105,951,688	23.18					14,352,989	62.79
1912	261,941	36,882.93	2.91	347,867	1.33	102,539,091	19.67					17,895,325	68.32
1913	382,663	29,699.88	1.65	324,586	.85	126,364,491	16.51					20,396,498	53.30
1914	360,569	35,863.89	2.06	358,486	.99	125,778,515	17.44					17,888,157	49.00
1915	427,495	37,836.33	1.83	412,745	.97	156,436,723	18.30					28,367,835	66.36
1916	559,840	47,028.69	1.74	488,742	.87	199,997,786	17.86					50,493,216	90.19
1917	655,250	50,280.80	1.59	525,923	.80	207,603,875	15.84					58,148,614	88.74
Lead:													
1903	37,943	3,927.02	2.14	1,627,030	42.88	674,495	.89	23,656,751	31.17			2,045,764	53.92
1904	49,826	4,050.00	1.68	1,770,893	35.54	568,065	.57	25,417,139	25.50			2,276,488	45.69
1905	41,033	4,200.00	2.11	1,566,610	38.18	614,360	.75	20,314,723	24.75			2,093,086	51.00
1906	64,437	5,025.42	1.61	1,522,107	23.62	1,783,886	1.38	33,962,526	26.35			3,419,072	53.06
1907	84,016	7,165.96	1.76	1,550,978	18.46	1,220,804	.73	32,727,688	19.48			3,150,507	37.50
1908	58,763	3,469.31	1.22	1,072,632	18.25	1,328,715	1.13	24,019,480	20.44			1,824,420	31.05
1909	93,934	6,407.52	1.41	1,404,731	14.95	1,817,083	.97	42,014,157	22.36			2,905,745	30.93
1910	92,103	6,599.90	1.48	1,463,613	15.89	1,226,984	.67	45,841,840	24.89			3,099,651	33.65
1911	107,576	7,545.79	1.45	1,899,737	17.56	1,396,430	.65	45,594,426	21.19			3,389,149	31.50
1912	103,999	6,917.15	1.37	2,247,050	21.61	2,315,119	1.11	45,506,496	21.88			3,954,713	38.02
1913	129,413	8,606.73	1.37	2,177,101	16.82	2,820,409	1.09	52,349,096	20.83			4,233,410	32.71
1914	127,958	15,739.60	2.54	1,695,790	13.25	2,558,128	.10	55,139,634	21.55			3,753,816	29.34
1915	149,258	20,952.08	2.90	1,887,105	12.64	3,142,093	1.05	62,004,656	20.77			4,853,965	32.52
1916	164,987	21,875.79	2.74	1,792,713	10.87	2,726,091	.82	60,007,367	18.18			6,442,945	39.05
1917	130,890	22,522.72	3.56	1,675,899	12.80	2,134,184	.82	51,356,311	19.62			6,845,802	52.30

Zinc:													
1905	90	3.00	.69	3,270	36.33	3,750	2.08	6,000	3.33	60,750	33.75	6,508	72.31
1906	8,921	219.98	.51	73,334	8.22	....	....	....	....	3,319,389	18.77	258,726	29.00
1908	3,153	3.39	.02	2,568	.81	....	....	4,415	.07	1,405,652	22.29	67,682	21.46
1909	18,969	363.43	.40	92,458	4.87	2,808	....	730,609	1.93	6,967,237	18.36	463,603	24.44
1910	12,710	5.09	....	140,279	11.04	....	....	890,545	3.50	8,742,135	34.39	587,115	46.19
1911	13,858	75.64	.11	39,300	2.83	9,944	.04	390,062	1.41	9,065,043	32.71	557,898	40.26
1912	14,992	253.92	.35	175,229	11.69	85,376	.28	938,813	3.13	10,716,314	35.74	908,775	60.62
1913	13,802	193.66	.29	134,762	9.76	68,216	.25	791,513	2.87	9,134,638	33.09	612,339	46.54
1914	11,869	74.39	.13	59,079	4.97	3,344	.01	261,569	1.10	8,885,621	37.43	498,021	41.12
1915	19,587	197.06	.21	164,515	8.40	12,787	.33	859,580	2.19	14,835,304	37.87	1,969,699	100.56
1916	18,433	126.88	.13	84,955	4.61	25,440	.07	390,460	1.05	14,020,354	38.03	1,970,450	106.89
1917	14,094	294.14	.43	131,615	9.34	168,483	.60	655,534	2.33	9,210,334	32.67	1,156,357	82.04
Copper-lead:													
1903	14,210	162.18	.24	225,268	15.85	908,208	3.20	2,591,636	9.12	....	....	358,270	25.21
1904	16,982	173.00	.21	231,178	13.61	1,001,543	2.95	2,450,856	7.22	....	....	371,244	21.86
1905	22,018	377.00	.35	330,855	15.03	1,320,555	3.00	3,501,732	7.95	....	....	580,202	26.35
1906	3,219	114.75	.73	37,600	11.57	253,546	3.90	806,175	12.40	....	....	122,827	37.80
1907	3,224	151.98	.97	80,976	25.12	272,819	4.23	807,832	12.53	....	....	153,965	47.75
1908	1,090	36.40	.69	22,838	20.95	88,064	4.04	223,921	10.27	....	....	33,886	31.09
1909	438	11.95	.56	7,941	18.13	65,668	7.50	81,603	9.32	....	....	16,423	37.49
1910	2,152	35.24	.34	62,154	28.88	154,924	3.60	570,955	13.27	....	....	79,089	36.75
1911	291	3.76	.26	9,021	31.00	29,354	5.04	45,872	7.88	....	....	10,591	36.39
1912	426	1.07	.05	15,008	35.23	60,167	7.06	86,777	10.18	....	....	23,083	54.18
1915	21	.52	.51	499	23.76	2,060	4.90	2,994	7.13	....	....	765	36.43
Lead-zinc:[a]													
1905	3,794	86.00	.47	34,370	9.06	....	....	361,413	4.76	1,911,577	25.19	152,514	40.20
1906	375	11.25	.62	6,563	17.50	....	....	37,500	5.00	168,750	22.50	17,127	45.67
1907	574	6.03	.22	9,415	16.40	....	....	46,361	4.04	258,784	22.54	24,064	41.92
1909	1,084	23.68	.45	13,179	12.16	1,593	.07	132,669	6.12	419,542	19.35	35,909	33.12
1910	12,714	278.90	.45	104,095	8.18	11,018	.04	1,069,848	4.21	4,217,287	16.59	294,132	23.14
1911	7,054	10.70	.03	98,549	13.97	3,009	.02	817,481	5.79	4,091,639	29.00	322,838	145.76
1916	6,042	337.73	1.16	106,244	17.58	105,367	.87	917,528	7.59	3,719,160	30.78	664,487	09.98
1917	12,924	571.00	.91	133,976	10.37	219,167	.84	1,944,380	7.52	7,657,236	29.62	1,130,287	87.46

[a] Lead-zinc ore concentrated in 1912-15 produced lead concentrate and zinc concentrate but no lead-zinc concentrate. In 1916-17 lead-zinc ore produced lead concentrate, zinc concentrate, and lead-zinc concentrate.

PRODUCTION.

The production of mineral substances has long been among the important industries of Utah. In addition to the metals, which alone are treated in this report, the State contains large deposits of coal and phosphate rock, important deposits of hydrocarbons and oil shale, and deposits of salines, building materials, and sulphur. In 1916, the nonmetallic mineral products were valued at \$8,690,172 and the metallic products at \$44,916,348, making a total of \$53,606,520.

PRODUCTION BY YEARS.

Production of metals on a commercial scale began in 1865. (See p. 118.) The quantity and value of the principal metals, by years, from 1865 to 1917, inclusive, is given in the table on pages 127–128, and the growth of the metal-mining industry is graphically shown in Plate XIII.

The increase in the metal output of the State since 1870, when railroad transportation reached Salt Lake City, has been rather uniform. There have, however, been several depressions of short duration, perhaps the most conspicuous being that in the middle nineties, when the rapid fall in the price of silver caused a considerable decrease in the output of both silver and lead, and that in 1907 to 1909 when the general commercial depression caused a considerable decrease in the value of the metal output. In 1915, 1916, and 1917 there was rapid increase due to war conditions. The discovery of a new deposit or the exhaustion of an old one has from time to time caused minor variations in the production curve, though usually these are not of large importance as regards the State production, as the falling off in one district is likely to be in part balanced by an increase in another. In the individual districts the production of a single mine is of course of far greater relative importance.

The relatively rapid rise in total metallic value (see Pl. XIII) since the late nineties is due in large part to the increase in the production of copper, principally from the Bingham district, though other districts have contributed important amounts.

The yearly tonnage of ore treated and the average value per ton are also shown in Plate XIII. Statistics regarding these items are complete only since 1902, but reliable estimates are available from 1888 to 1892. There has been a very rapid increase in the amount of ore produced and a very rapid decrease in the average value per ton, which dropped from more than \$15 in 1892 to \$4.39 in 1913.

The decrease in the value per ton may be attributed principally to the great advances made in mining and metallurgic processes, which have made it profitable to mine and treat material that but a few years ago was not regarded as ore, and to the exhaustion of the bonanza portions of many of the old mines. The rapid decrease in the last few years is due, in large part, to increase in the amount of low-grade copper ore treated. In the future it is likely to be much less marked, though it will doubtless continue and will be welcomed

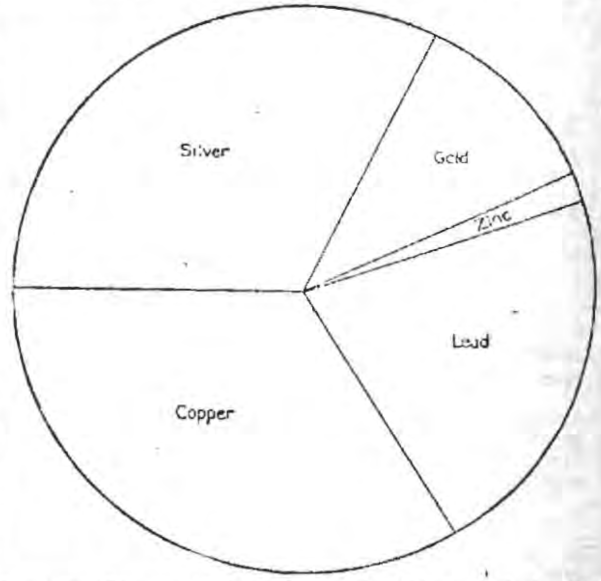
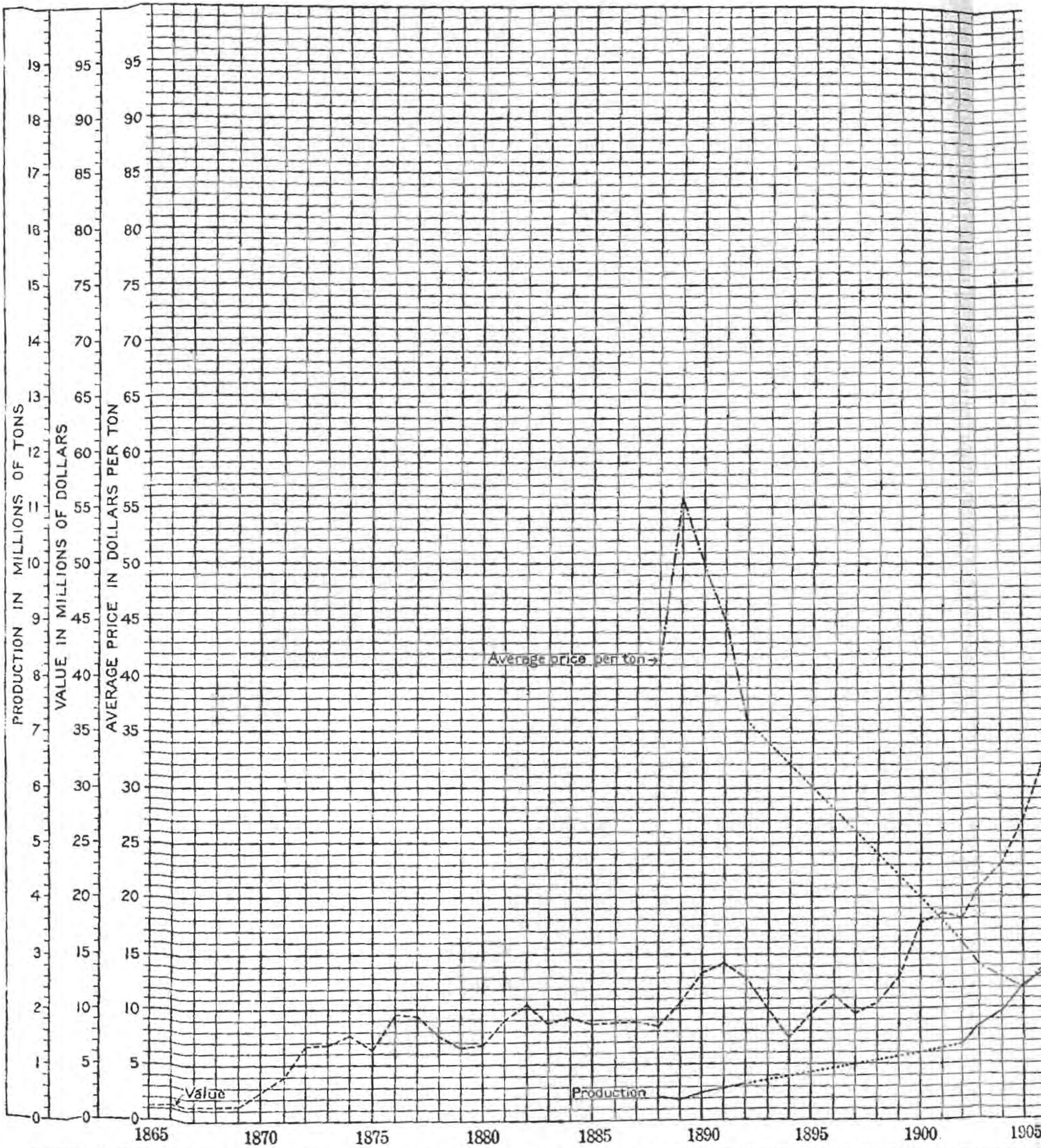


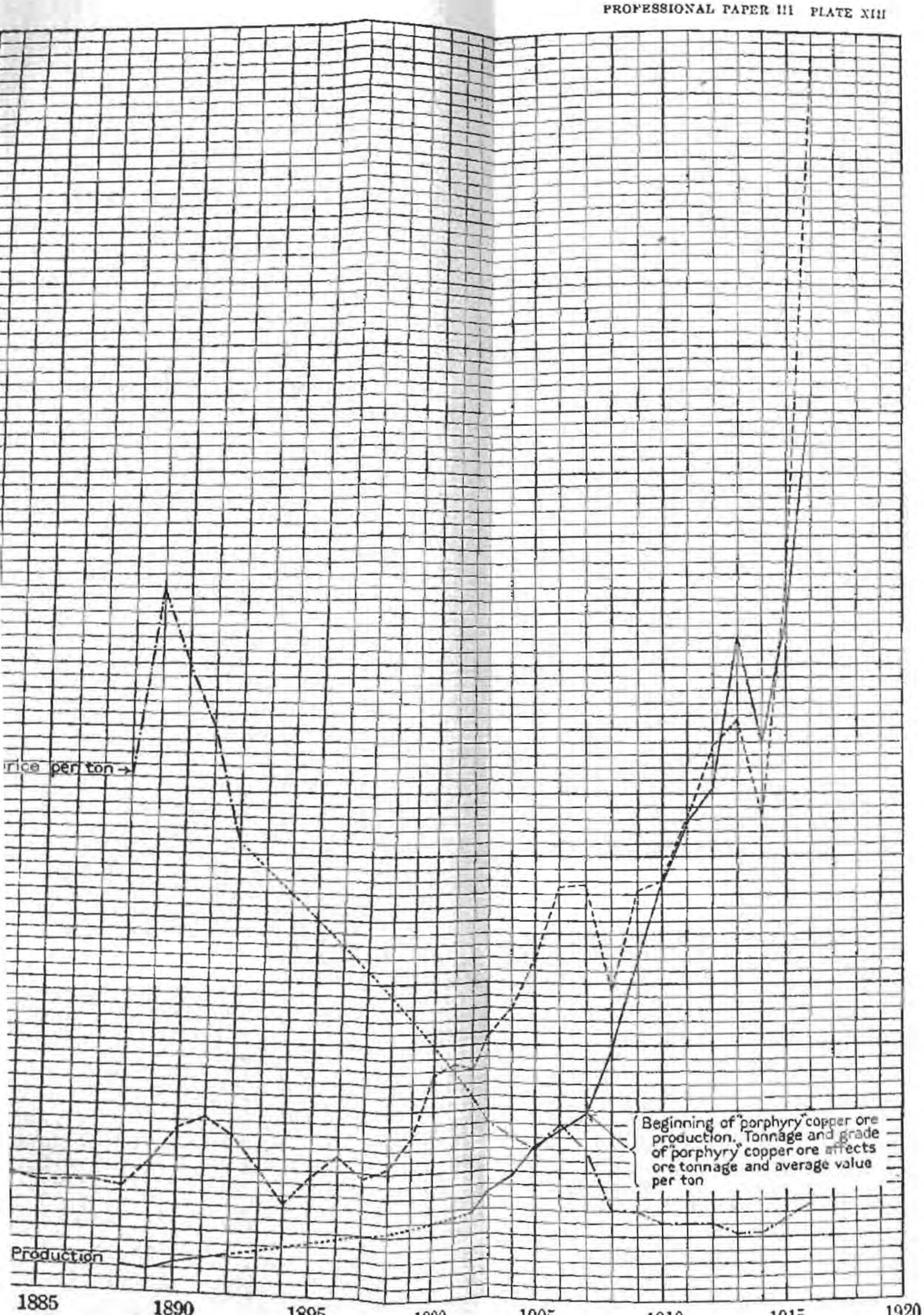
FIGURE 12.—Diagram showing relative value of the principal metals produced in Utah, 1865–1916.

so far as it means an improvement in mining and metallurgic practices, for even a slight decrease in the value of material that can be commercially treated adds materially to the amount of the ore available.

The total value of the principal metals produced to the close of 1917, amounting to \$916,155,337, is distributed as follows: Silver, \$271,788,824; copper, \$346,681,440; lead, \$188,715,846; gold, \$93,119,333; and zinc, \$15,849,894. To obtain the total value of all metals produced it would be necessary to add to these figures the output of less important metals, accurate statistics of which are for the most part not available. The relative value of the different metals is shown graphically in figure 12.



CURVES SHOWING BY YEARLY AVERAGES THE VALUE OF THE METALLIC OUTPUT OF THE MINES OF UTAH, THE TONS OF ORE PRODUCED,



)UTPUT OF THE MINES OF UTAH, THE TONS OF ORE PRODUCED, AND THE AVERAGE VALUE PER TON.

Wells Fargo & Co., estimates confirmed by smelter totals. Refiners' figures for 1886 are 500,000 pounds; for 1889, 65,467 pounds.

Quantity of ore sold or treated in Utah, 1865–1917, and total metals recovered.

Year.	Quantity (short tons).	Gold.[a]		Silver.[a]		Copper.[b]		Lead.[b]		Recoverable zinc.[b]		Total value.
		Fine ounces.	Value.	Fine ounces.	Value.	Pounds.	Value.	Pounds.	Value.	Pounds.	Value.	
1864		(c)						(d)				
1865		[e] 2,700	$55,814	[e] 450	$602							$56,416
1866		[e] 4,100	84,755	[e] [f] 800	1,071							85,826
1867		[e] 4,670	96,537	[e] 812	1,080							97,617
1868		[e] 8,000	165,375	[e] 1,600	2,122	(g)		(g)				167,497
1869		[e] 9,068	187,452	[e] 1,750	2,319							189,771
1870	[h] 9,633	[e] 14,512	300,000	[e] [h] 473,182	628,386	[h] 100,000	$21,180	8,333,000	$500,000			1,449,566
1871		[e] 11,063	228,692	[e] [h] 1,709,811	2,265,500	[h] 390,000	94,068	10,000,000	608,000			3,196,260
1872		[h] 8,500	175,711	2,981,521	3,941,571	[h] 600,000	213,360	23,570,000	1,484,910			5,815,552
1873		2,536	52,426	3,157,435	8,725,774	876,000	245,000	30,000,000	1,896,000			5,919,200
1874		[i] 13,608	281,293	2,904,246	3,630,308	[h] 374,000	82,280	40,000,000	2,440,000			6,433,881
1875		8,793	181,765	2,383,809	2,955,923	[h] 716,797	162,713	38,000,000	2,204,000			5,504,401
1876		8,820	182,326	4,436,982	5,146,900	947,000	198,870	50,000,000	3,050,000			8,578,096
1877		17,323	358,108	4,359,733	5,231,644	[j] 641,200	121,828	48,388,000	2,661,340			8,372,920
1878		13,394	276,874	4,132,313	4,752,160	[j] 764,397	126,890	43,254,000	1,557,144			6,713,068
1879		15,730	325,180	3,665,600	4,105,472	[j] 258,800	48,137	28,740,000	1,178,340			5,657,129
1880	[k] 142,682	8,020	165,788	3,663,183	4,212,660	[j] 86,000	18,404	30,428,000	1,521,400			5,918,252
1881		6,982	144,331	4,958,345	5,602,930	[j] 385,600	70,179	47,946,000	2,301,408			8,118,848
1882		9,039	186,853	5,435,444	6,196,406	605,880	115,723	59,874,000	2,933,826			9,432,808
1883		6,772	140,000	4,388,541	4,915,166	341,885	56,411	66,660,000	2,866,380			7,977,957
1884	[l] 149,062	5,805	120,000	5,263,157	5,842,104	265,526	34,518	60,864,000	2,251,968			8,248,590
1885		8,707	180,000	5,232,557	5,598,836	126,199	13,629	51,318,000	2,001,402			7,793,867
1886		10,449	216,000	5,030,958	4,980,648	[m] 2,408,000	267,238	48,664,000	2,335,872			7,799,758
1887		10,643	220,000	5,414,185	5,305,901	2,500,000	345,000	45,800,000	2,061,000			7,931,901
1888	[l] 190,701	14,029	290,000	5,414,062	5,089,218	2,131,047	358,016	44,566,000	1,960,904			7,698,138
1889	[l] 175,700	24,187	500,000	7,000,000	6,580,000	[m] 2,060,000	278,207	62,360,000	2,432,040			9,790,247
1890	[l] 249,536	32,895	680,000	8,000,000	8,400,000	1,006,636	157,035	68,264,000	3,071,880			12,308,915
1891	[l] 299,412	31,444	650,000	8,750,000	8,662,500	1,562,098	199,949	86,720,000	3,728,960			13,241,409
1892	[l] 331,213	31,936	660,175	8,100,000	7,047,000	2,209,428	256,294	91,106,000	3,644,240			11,607,709
1893		41,293	853,600	7,196,300	5,613,114	1,135,330	122,616	70,086,000	2,593,182			9,182,512
1894		41,991	868,031	5,891,901	3,711,898	1,147,570	109,019	46,380,000	1,530,540			6,219,488
1895		66,419	1,373,000	7,468,100	4,854,265	2,184,708	233,764	62,610,000	2,003,520			8,464,549

[a] Director of Mint estimates unless otherwise indicated.
[b] U. S. Geol. Survey Mineral Resources. Output reported by smelters and refiners unless otherwise indicated.
[c] Californians find placer gold at Bingham, and in spring of 1865 gravel washing actively taken up. See U. S. Geol. Survey Prof. Paper 38, p. 83, 1905.
[d] Lead was first produced from ore reduced in a furnace built near the Rollins or Lincoln mine, Beaver County, in the fifties, by a Mormon named Isaac Grundy. See Eissler, M., The metallurgy of argentiferous lead, preface, 1891.
[e] Boutwell, J. M., U. S. Geol. Survey Prof. Paper 38, p. 83, 1905, estimated that during opening period of placer mining in Bingham, including 1871, the production of gold amounted to $1,000,000.
[f] In 1864, the Aug. 29 issue of the Daily Union Vedette, Camp Douglas, Utah, records the first lead-silver bullion produced near Stockton, Utah; Sept. 17, 1866, first successful separation of silver from lead bullion by J. W. Gibson, Stockton, Utah.
[g] H. H. Bancroft, History of Utah, p. 741, records that "the first shipment of ore from Utah was a carload of copper ore from Bingham Canyon in June (1868), shipped to Baltimore." No figures available.
[h] Raymond, R. W., Mineral Resources west of Rocky Mountains, 1870–1872. Estimated by V. C. Heikes from shipments of ore and matte reported by Raymond and from railroad statements.
[i] Includes gold in silver bullion shipped from Germania refinery; probably accumulation from ores of several districts in Utah with Nevada eliminated.
[j] Utah Central Railroad statement, 1872–1880; metal production for years 1876–1881; estimates by V. C. Heikes.
[k] Tenth Census United States, vol. 13, pp. 313–316, 1885.
[l] Reports of Director of Mint, 1884–1892.
[m] Wells Fargo & Co., estimates confirmed by smelter totals. Refiners' figures for 1886 are 500,000 pounds; for 1889, 65,467 pounds.

Quantity of ore sold or treated in Utah, 1865–1917, and total metals recovered—Continued.

Year.	Quantity (short tons).	Gold.		Silver.		Copper.		Lead.		Recoverable zinc.		Total value.
		Fine ounces.	Value.	Fine ounces.	Value.	Pounds.	Value.	Pounds.	Value.	Pounds.	Value.	
1896	....	91, 906	$1, 899, 900	8, 827, 600	$6, 002, 768	3, 502, 012	$378, 217	71, 156, 000	$2, 134, 680	....	....	$10, 415, 565
1897	....	83, 500	1, 726, 100	6, 265, 600	3, 759, 360	3, 919, 010	470, 281	81, 074, 000	2, 918, 664	....	....	8, 874, 405
1898	....	110, 556	2, 285, 400	6, 485, 900	3, 826, 681	3, 750, 000	465, 000	78, 598, 000	2, 986, 724	....	....	9, 563, 805
1899	....	166, 933	3, 450, 800	7, 093, 300	4, 255, 980	9, 584, 746	1, 638, 991	59, 974, 000	2, 698, 830	....	....	12, 044, 601
1900	....	192, 155	3, 972, 200	9, 267, 600	5, 745, 912	18, 354, 726	3, 046, 885	96, 088, 000	4, 227, 872	....	....	16, 992, 869
1901	....	178, 513	3, 690, 191	10, 760, 800	6, 456, 480	20, 116, 979	3, 359, 535	99, 740, 000	4, 288, 820	....	....	17, 795, 026
1902	1, 114, 785	174, 522	3, 607, 686	11, 842, 015	6, 176, 795	23, 939, 901	2, 920, 668	107, 828, 000	4, 420, 948	....	....	17, 126, 097
1903	1, 412, 379	[a] 210, 144	4, 344, 069	[a] 12, 204, 011	6, 518, 162	[a] 32, 847, 656	4, 542, 831	[a] 100, 742, 633	4, 311, 785	....	....	19, 716, 847
1904	1, 716, 947	[a] 202, 657	4, 189, 292	[a] 12, 049, 446	6, 898, 308	[a] 46, 417, 234	5, 802, 154	[a] 116, 479, 764	5, 095, 989	[b] 332, 924	$16, 979	[b] 22, 002, 722
1905	2, 181, 061	[a] 248, 692	5, 140, 920	[a] 11, 036, 471	6, 666, 028	[a] 57, 298, 054	8, 938, 496	[a] 103, 882, 009	4, 882, 454	[b] 7, 102, 547	419, 050	[b] 26, 046, 948
1906	2, 348, 819	[a] 252, 439	5, 218, 386	[a] 11, 550, 634	7, 738, 925	[a] 56, 593, 576	10, 922, 560	[a] 125, 342, 836	7, 144, 542	6, 474, 615	394, 952	31, 419, 365
1907	2, 669, 696	[a] 247, 760	5, 121, 646	[a] 10, 990, 076	7, 253, 450	[a] 64, 256, 884	12, 851, 377	[a] 115, 938, 037	6, 144, 716	5, 452, 916	321, 722	31, 692, 911
1908	3, 658, 957	[a] 179, 055	3, 701, 387	[a] 8, 451, 338	4, 479, 209	[a] 86, 843, 812	11, 463, 383	[a] 88, 777, 498	3, 728, 655	1, 460, 554	68, 646	23, 441, 280
1909	5, 122, 589	[a] 203, 492	4, 206, 548	[a] 11, 717, 172	6, 092, 929	[a] 108, 947, 811	14, 163, 215	[a] 148, 486, 463	6, 384, 918	9, 860, 778	532, 482	31, 380, 092
1910	6, 389, 398	[a] 195, 052	4, 032, 085	[a] 10, 466, 971	5, 652, 164	[a] 127, 597, 072	16, 204, 828	[a] 123, 324, 635	5, 426, 284	16, 367, 104	883, 824	32, 199, 185
1911	7, 268, 530	[a] 227, 217	4, 696, 998	[a] 12, 473, 787	6, 611, 107	[a] 146, 960, 827	18, 370, 103	[a] 136, 496, 750	6, 142, 354	17, 840, 261	1, 016, 895	36, 837, 457
1912	7, 770, 270	[a] 206, 360	4, 265, 851	[a] 13, 835, 903	8, 509, 080	[a] 137, 307, 485	22, 655, 735	[a] 140, 311, 135	6, 314, 001	17, 067, 177	1, 177, 635	42, 922, 302
1913	10, 202, 566	[a] 172, 468	3, 565, 229	[a] 13, 084, 835	7, 903, 240	[a] 161, 445, 962	25, 024, 124	[a] 166, 126, 790	7, 309, 579	18, 857, 827	1, 056, 038	44, 858, 210
1914	8, 544, 014	[a] 157, 961	3, 265, 347	[a] 11, 154, 916	6, 168, 669	[a] 152, 034, 002	20, 220, 522	[a] 171, 323, 137	6, 681, 602	15, 989, 267	815, 453	37, 151, 593
1915	10, 451, 445	[a] 174, 590	3, 609, 109	[a] 12, 313, 205	6, 242, 795	[a] 187, 671, 188	32, 842, 458	[a] 199, 967, 437	9, 398, 470	24, 292, 240	3, 012, 238	55, 105, 070
1916	13, 920, 643	[a] 172, 938	3, 574, 947	[a] 13, 253, 037	8, 720, 498	[a] 240, 275, 222	59, 107, 705	[a] 201, 490, 075	13, 902, 815	29, 572, 528	3, 962, 719	89, 268, 684
1917	15, 358, 481	[a] 162, 305	3, 355, 156	[a] 13, 479, 133	11, 106, 806	[a] 246, 674, 153	67, 342, 044	[a] 178, 521, 958	15, 352, 888	21, 286, 871	2, 171, 261	99, 328, 155
Total [c] [d]	....	4, 504, 646	93, 119, 333	366, 020, 527	271,788,824	1, 962, 162, 413	346, 681, 440	3, 975, 600, 157	188,715,846	191, 957, 609	15, 849, 894	916, 155, 337

[a] Mine production, U. S. Geol. Survey Mineral Resources, 1903–1917; figures collected from the mines.
[b] Previous figures of the U. S. Geol. Survey are corrected.
[c] For a complete table of copper statistics, according to refiners' figures, of the United States, by States, from 1845 to 1910 reference is made to U. S. Geol. Survey Mineral Resources, 1910, pp. 170–173, 1911, and for lead in Utah from 1877–1912 see same publication for 1912, pp. 339–340, 1913.
[d] These totals are largely smelter and refiners' totals, which are less than mine output shown in district totals on account of smelter losses.

Metals produced in Utah, 1864–1917, by periods.

Period.	Quantity (short tons).	Gold.		Silver.		Copper.		Lead.		Zinc (recoverable).		Total value.
		Fine ounces.	Value.	Fine ounces.	Value.	Pounds.	Value.	Pounds.	Value.	Pounds.	Value.	
1865–1880	....	150, 837. 00	$3, 118, 096	33, 873, 227	$40, 603, 492	3, 754, 194	$1, 332, 730	350, 713, 000	$19, 101, 134	....	....	$64, 155, 452
1881–1890	....	129, 508. 00	2, 677, 184	56, 137, 249	58, 511, 209	11, 830, 773	1, 695, 956	556, 316, 000	24, 216, 680	....	....	87, 101, 029
1891–1900	....	858, 135. 00	17, 739, 206	75, 346, 301	53, 479, 478	47, 349, 628	6, 921, 016	743, 792, 000	28, 467, 212	....	....	106, 606, 912
1901–1910	....	2, 092, 325. 52	43, 252, 210	111, 068, 934	63, 932, 450	624, 858, 979	91, 169, 047	1, 130, 541, 875	51, 829, 111	47, 051, 438	2, 637, 655	252, 820, 473
1911–1917	73, 515, 949	1, 273, 841. 32	26, 332, 637	89, 594, 816	55, 262, 195	1, 272, 368, 839	245, 562, 691	1, 194, 237, 282	65, 101, 709	144, 906, 171	13, 212, 239	405, 471, 471
		4, 504, 646. 84	93, 119, 333	366, 020, 527	271, 788, 824	1, 962, 162, 413	346, 681, 440	3, 975, 600, 157	188, 715, 846	191, 957, 609	15, 849, 894	916, 155, 337

In the early days of mining silver was the most important metal. In recent years, however, the precious metals have been of much less relative importance. In 1917 copper alone yielded considerably more than 67 per cent of the total value.

PRODUCTION BY DISTRICTS.

The table on page 130 gives the production of each important district. The total value given is somewhat larger than that given in the table by years (pp. 127–128) and is doubtless less

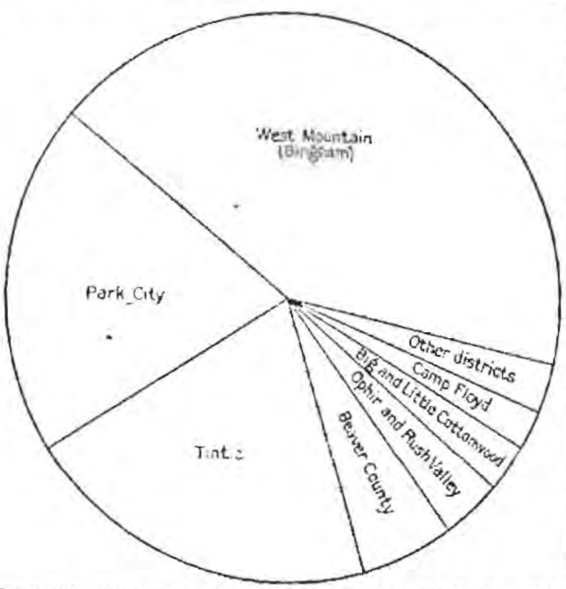


FIGURE 13.—Diagram showing relative value of the metal output of the principal mining districts of Utah, 1865–1916.

accurate, the present table having been compiled from many sources. The difference, however, is but a small fraction of 1 per cent, and the figures for the individual districts may be regarded as essentially accurate. Figure 13 shows the relative rank of the largest districts.

NET PROFITS.

It is impossible to get data for even an approximate comparison of the amount of money expended in mining operations and the value of the metal produced. There is no doubt that the value of the metals is in excess of the expenditures, but if all expenditures of time and money are considered the excess will not be as great as many believe. The profits of a relatively few companies have been very large, but, as in most mining regions, the great majority of operations have resulted in losses. These losses are due to many causes, ranging from those incident to thoroughly legitimate prospecting under capable management to operation of individuals and companies that lack both technical skill and honesty. The table on page 130 shows the known dividends of several of the more important mining districts, and the following list gives the names by districts of companies that have paid dividends.

Tintic district.

Ajax.	Iron Blossom.
Beck Tunnel.	Lower Mammoth.
Bullion Beck.	Mammoth.
Carisa.	May Day.
Centennial-Eureka.	Mount View (Yankee).
Chief Consolidated.	Opohonga.
Colorado.	Sioux Consolidated.
Dragoon.	South Swansea.
Eagle and Blue Bell.	Swansea
Eureka Hill.	Tetro (Plutus).
Gemini-Keystone.	Tintic Standard.
Godiva.	Uncle Sam Consolidated.
Gold Chain.	Victoria.
Grand Central.	Yankee Consolidated.
Hamburg.	

Gold Mountain district.

Annie Laurie.

Camp Floyd (Mercur district).

Boston-Sunshine.	Geyser-Marion.
Consolidated Mercur.	Sacramento.

Bingham district (West Mountain).

Bingham New Haven.	U. S. Mining Co.
Brooklyn Lead.	Utah Apex.
Dalton & Lark.	Utah Consolidated.
Old Telegraph and Galena.	Utah Copper.
Petro.	Utah Metal and Tunnel.

Park City region.

Crescent.	Little Bell.
Daly.	Ontario.
Daly-Judge.	Silver King Coalition.
Daly West.	Silver King Consolidated.

Washington County (Silver Reef district).

Barbee & Walker.	Leeds.
Christy.	Stormont.

Silver Islet district.

Gethin Leroy.

Ophir and Rush Valley districts.

Chicago.	Honorine.
Cliff.	Mono.
Hidden Treasure.	Northern Light.

Little Cottonwood and Big Cottonwood districts.

Cardiff.	Joab Lawrence.
Columbus Consolidated.	Maxfield.
Emma.	Prince of Wales.
Flagstaff.	South Hecla.

Production in Utah mining districts.

District.	Period.	Ore (short tons).	Gold. Fine ounces.	Gold. Value.	Silver. Fine ounces.	Silver. Value.	Copper. Pounds.	Copper. Value.	Lead. Pounds.	Lead. Value.	Zinc (recoverable). Pounds.	Zinc (recoverable). Value.	Total value.[a]	Dividends.	Number of mines that have paid dividends.
Bingham (West Mountain)	1865-1917		1,515,015.90	$31,318,190	48,415,824	$35,655,120	1,658,635,866	$296,608,106	1,058,092,538	$52,429,453	40,052,718	$3,678,727	$419,690,656	$88,501,870	9
Park City	1870-1917		211,253.81	4,367,178	135,299,810	99,202,856	31,028,556	4,917,960	1,252,444,864	58,271,893	66,191,185	4,951,107	169,814,024	43,585,698	8
Tintic	1869-1917		1,574,942.11	32,556,936	125,271,652	83,313,232	171,493,635	27,552,435	752,049,426	35,358,411	16,803,653	1,390,790	180,401,804	31,959,096	29
Beaver County	1860-1917		37,139.51	767,739	21,160,006	19,588,392	49,638,383	8,478,593	411,403,954	17,980,774	33,507,519	2,577,029	49,392,527	7,747,704	4
Ophir and Rush Valley	1870-1917		28,394.15	486,978	14,250,680	11,818,608	23,026,554	4,044,373	275,890,008	14,643,608	4,823,331	442,091	31,536,438	1,235,000	6
Big and Little Cottonwood	1867-1917	429,495	24,213.05	500,529	13,140,345	13,215,139	9,855,917	1,741,962	180,616,785	10,225,640	320,934	39,283	25,722,553	2,474,060	8
Camp Floyd	1871-1917		920,842.57	19,035,512	[b] 48,760	57,512							19,093,024	3,881,323	4
Washington County	1875-1917		634.14	13,110	7,366,657	8,079,416	10,609,492	1,536,775	[c] 43,669	2,315			9,631,616	[d] 900,000	4
American Fork	1870-1917	64,217	13,127.80	271,373	1,887,596	2,014,647	159,091	30,077	28,586,796	1,574,129	46,911	4,824	3,895,050	8,000	1
Piute County	1868-1917	485,740	150,595.75	3,113,089	704,748	490,999	[e] 73,616	14,049	[e] 847,883	61,006			3,679,143	439,561	1
Lucin	1870-1917	152,495	104.43	2,158	225,136	253,484	16,577,321	2,702,258	4,749,122	294,756	34,680	3,537	3,256,193		
Fish Springs	1891-1917	18,459	449.60	9,296	2,499,603	1,627,832	4,315	681	16,069,128	678,655			2,316,464	363,720	2
North Tintic	1902-1917	56,483	7.67	158	36,539	23,124	182	23	11,406,680	577,742	18,792,296	1,246,697	1,847,744		
Carbonate	1891-1917	4,377	912.21	18,857	102,747	63,496	2,589,245	395,655	1,328	114			478,122		
Mount Nebo	1870-1917	4,065	15.29	317	37,226	24,295	1,526	274	1,932,683	90,780	788,679	75,096	190,762		
Argenta	1905-1917	1,662	8.46	175	9,559	6,037	494	75	803,005	43,525			49,812		
Ashbrook	1899-1917	712	70.88	1,464	31,099	18,689							20,153		
Blue Bell	1891-1917	249	5.14	105	4,945	3,179			284,557	12,731			16,015		
Box Elder	1908-1917	151	5.25	106	189	105	23,080	3,073	7,097	498			3,782		
Calumet	1916-1917	684	2.00	41	850	641	78	21	290,780	22,720			23,423		
Clifton	1892-1917	71,576	12,199.06	252,177	163,380	134,213	1,911,840	520,791	520,721	44,622			951,803		
Colorado River	1911-1916	100	47.51	982	11	6							988		
Columbia	1908-1917	3,262	18.75	388	9,552	6,030	4,907	782	1,265,974	71,670	41,500	4,262	83,132		
Detroit (Juab and Millard Counties)	1904-1917	1,511	538.98	11,143	5,127	2,991	169,250	31,675					45,809		
Dugway	1916-1917	167	1.36	28	906	630	9,067	2,428	114,773	8,479			11,565		
Erickson	1916-1917	264	37.82	782	50,314	33,634	364	92	29,646	2,549			37,057		
Free Coinage	1917	54	.17	3	362	298			28,765	2,474			2,775		
Gold Springs	1907-1917	12,939	2,482.26	51,314	8,962	5,048							56,362		
Henry	1902-1916	1,607	416.96	8,619	28,332	16,104	3,056	752	96	7			25,482		
Imperial (Garfield County)	1914-1917	54	87.09	1,800	46	36	2,749	751					2,557		
Lake Side	1903-1917	333	.95	19	928	638	817	201	78,616	6,050			6,908		
La Sal—Big Indian	1907-1917	166	21.04	435	7,569	5,393	22,963	5,355	236	11			11,194		
Leamington	1903-1917	387	2.20	45	1,682	1,052	36	6	126,963	6,198			7,301		
Lost Springs	1906-1917	42	6.33	131	233	159	6,744	1,788	218	12			2,090		
Miners Basin	1903-1913	385	1,172.71	24,243	6,143	3,322							27,565		
Paradise (Cache County)	1914-1917	182			188	129	10,762	2,741	15,277	776	17,883	2,227	5,873		
Park Valley	1902-1917	67,755	17,945.33	370,962	8,968	5,141	49,075	6,442	21,867	1,115			383,660	49,000	1
Promontory	1907-1917	13,714			378	248	1,078	215	1,256,021	91,220	5,725,336	723,990	815,673	109,000	1
Santaquin	1910-1917	470	.47	10	3,492	2,019	208	34	206,522	9,576			11,639		
Silver Islet	1908-1917	954	46.93	971	122,838	70,124	70,082	10,143	479,835	20,969			102,207	7,500	1
Silver Lake	1902-1914	50	8.10	167	2,420	1,428	12	1	37,810	1,831			3,427		
Smelter	1908-1917	80,623	812.40	16,793	110,515	80,042	753,925	131,445	2,218,632	166,368	4,751,909	502,309	896,957		
Spring Creek	1902-1915	6,992	2,048.05	42,337	6,587	2,951	1,327	232	5,609	263			45,783		
Stateline	1901-1917	13,102	3,034.42	62,726	95,678	51,638	88	12	75,000	3,075			117,451		
Summerville	1902-1915	169			725	381	108	29	8,262	340	59,075	7,325	8,075		
Third Term	1916-1917	317	.17	4	1,236	1,086	2,623	661	77,951	6,618			8,369		
West Tintic	1902-1917	4,180	1,197.65	24,757	35,085	21,159	10,456	1,907	1,437,322	90,395			139,018		
White Canyon (San Juan)	1915-1917	96	6.06	126	384	271	49,889	12,676					13,073		
Wild Cat Range	1914-1917	182	.85	17	2,340	1,247	4,382	648	11,791	554			2,466		

[a] Commercial values used for metals produced in each calendar year.
[b] The yearly production of silver, between 1871 and 1881, was estimated to be 46,000 ounces. (See U. S. Geol. Survey Sixteenth Ann. Rept., pt. 2, p. 355, 1895.) Since that period the gold ores mined carried very little silver, and only 2,760 ounces were reported by producers whose ores yielded a total of 920,741.10 ounces of gold from 1890 to 1913, inclusive.
[c] No records were preserved by producers of occasional lots of lead ore shipped from the Black Warrior and Dixie mines in the Tutsagubet district.
[d] Dividends paid by operators in the Silver Reef section are known to be incomplete. A fair estimate is given by competent authorities.
[e] Between 1904 and 1911 the production was 44,244 pounds of copper and 134,361 pounds of lead as reported by producers. Prior to this period no record of production was found.

Park Valley district.

Century.

Promontory district.

Lakeview.

Beaver County.

Horn Silver. Utah Leasing (Cactus tailing).
Moscow.
Newhouse.

Fish Springs district.

Galena. Utah.

American Fork district.

Pacific Gold.

The relative importance of the several regions as dividend payers is shown graphically in figure 14. The Bingham district has yielded the most in dividends, though this leadership has only recently been taken from the Park City district. In the ratio of dividends paid to the value of the metals produced the Park City district has the best record of the important camps of the State.

The total of $182,245,816 in dividends to the end of 1917 from mining operations is large, but if from this should be subtracted all the losses in labor and material over a period of 50 years the net results would be less impressive.

That there are large losses should not discourage either mining operations or mining investments, but it should cause investors to look carefully to the character of their investments and to remember that there is a great difference in mines and that relatively few ever reach a dividend basis. The layman investor should also realize that there is no necessary relation between the value of metal produced and the amount paid to the stockholders. Mines can be cited where the value of the metals produced ran into millions of dollars, but where, nevertheless, the operations resulted in a total loss of the investment. A certain class of promoters are wont to cite the metal production of a district or property as recommending it, but the point of interest to the investor should be the dividends that may be expected to result from the operation of the mine.

PRODUCTION OF THE PRINCIPAL METALS.

GOLD.

In Utah, as in many of the Western States, the earliest important metal production was of placer gold. Placer mining was begun at Bingham Canyon in 1865 and for some years yielded an important production, totaling about $1,000,000. No other district has obtained important amounts from placers, though placer gold has been produced on Colorado, Green, and San Juan rivers; from the La Sal and Henry mountains; and from the vicinity of Marysvale; and placer ground is reported from the west base of the Tushar Range and in other localities.

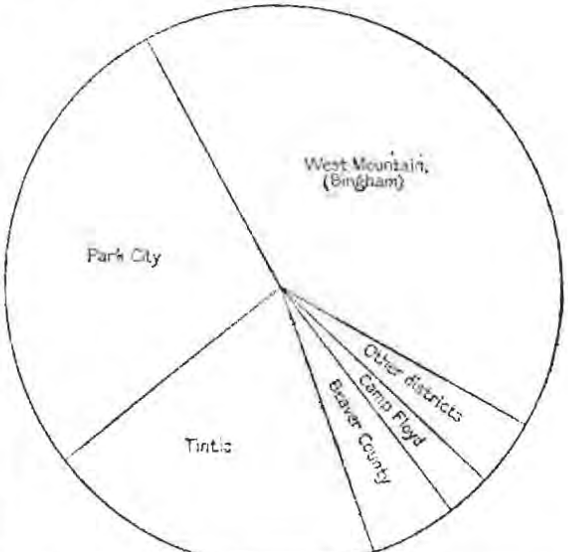


FIGURE 14.—Diagram showing the relative amounts paid in dividends by companies in the larger mining districts of Utah, 1865–1916.

Gold produced in Utah to end of 1917, by districts.

District.	Fine ounces.	Value.
Tintic	1, 574, 941. 78	$32, 556, 936
West Mountain	1, 515, 018. 90	31, 318, 190
Camp Floyd	920, 842. 87	19, 035, 512
Park City	211, 263. 77	4, 367, 178
Gold Mountain	143, 561. 26	2, 967, 674
Beaver County	37, 139. 51	767, 739
Ophir and Rush Valley	28, 395. 07	586, 978
Big and Little Cottonwood	24, 213. 05	500, 529
American Fork	13, 127. 80	271, 373
Other districts	36, 146. 96	747, 224
	4, 504, 650. 97	93, 119, 333

Gold is present in practically all the metal deposits of the State except the iron ores and the "sandstone" deposits of the Plateau region. In but few districts, however, is the most important metal production in gold, and only one of these, Camp Floyd (Mercur), ranks among the important gold-producing districts of the country; others are the districts in the Tushar Range and the Gold Springs–State Line section. Gold, however, is produced in several districts where other metals constitute the more valuable part of the total output, notably in the Tintic and

West Mountain (Bingham) districts, in both of which the yield of gold has been greater than in the Mercur district. The relative

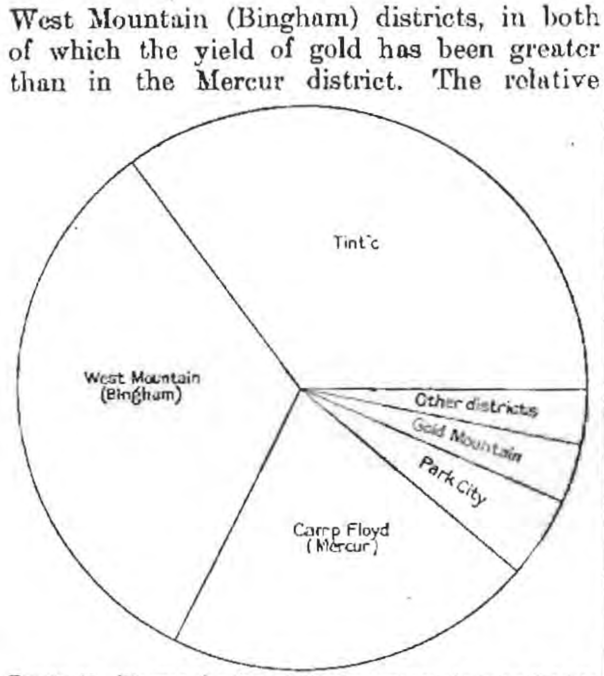


FIGURE 15.—Diagram showing relative importance of mining districts of Utah in production of gold, 1865–1916.

importance of the different districts in the production of gold to the close of 1916 is graphically shown in figure 15.

Although gold was the first metal to be produced in important amounts in the State its output was not large till the late eighties, when the Tintic district became important, and did not pass the million-dollar mark till the early nineties, when the cyanide process was successfully applied to the ores of the Mercur district.

The yearly variation in the production of gold is shown in figure 16. After 1890 the increase in production was rapid and, with the exception of a few years, continuous till 1906. Since 1906 there has been a general decline, which was very considerable during the depression of 1907–8 and which, though in part retrieved in the next few years, has not yet been wholly recovered from.

The decrease due to the exhaustion of the most important mine in the Mercur district has been partly offset by an increase from other districts and from other ores, notably copper ores.

The accompanying table shows the character of the different ores from which gold has been recovered and the amount recovered from each for the period 1904–1917.

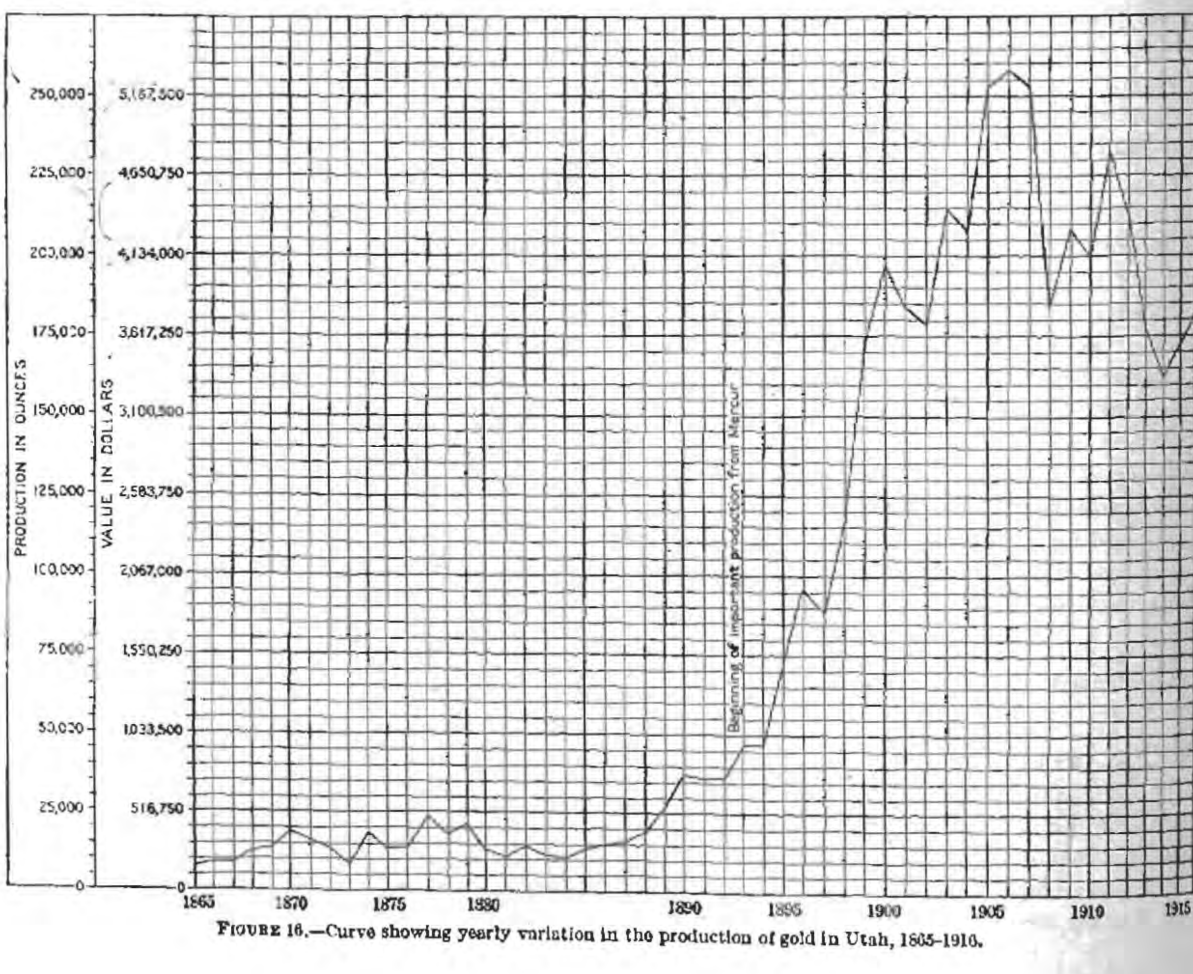


FIGURE 16.—Curve showing yearly variation in the production of gold in Utah, 1865–1916.

Gold produced in Utah, 1904–1917, by kinds of ore, in fine ounces.

Year.	Placers.	Dry or siliceous ore.	Copper ore.	Lead ore.	Zinc ore.	Copper-lead-zinc ore.	Copper-lead ore.	Lead-zinc ore.	Total.
1904......	65.00	58,863.00	92,271.00	3,468.00	6.00	2,552.00	45,428.00	82.00	202,675.00
1905......	322.00	64,383.00	125,897.00	17,805.00	95.00	1,682.00	36,818.00	1,690.00	248,692.00
1906......	416.63	62,866.25	120,766.53	12,785.54	50.00	4,783.07	50,215.63	555.77	252,439.42
1907......	438.35	42,853.89	158,154.83	46,170.73	....	....	123.77	18.06	247,759.63
1908......	440.69	47,439.15	111,086.12	19,986.36	1.35	....	90.17	10.76	179,054.60
1909......	122.15	48,931.33	117,265.85	35,858.36	....	....	102.89	1,211.18	203,491.76
1910......	192.53	47,216.85	113,978.49	28,327.58	17.72	....	154.63	5,164.31	195,052.11
1911......	272.54	[a]78,912.69	117,247.94	25,709.04	1.60	....	114.16	4,959.31	227,217.28
1912......	274.77	[b]71,243.22	105,720.03	24,310.76	102.17	....	171.58	4,538.01	206,360.54
1913......	92.88	[c]32,830.03	100,093.39	34,213.80	....	....	70.58	5,167.27	172,467.95
1914......	59.55	[d]18,274.43	97,955.32	33,094.69	....	....	78.17	8,499.00	157,961.16
1915......	46.34	[e]9,248.67	101,247.86	45,541.34	32.85	....	65.89	18,407.70	174,590.65
1916......	60.47	[f]9,122.41	113,396.52	33,535.63	....	....	421.68	16,401.35	172,938.06
1917......	5.42	[g]20,394.61	94,844.85	27,115.49	....	....	92.25	19,853.05	162,305.67

[a] Siliceous gold and silver ores contained 58,204.33 ounces; silver ores, 19,941.87 ounces; oxidized gold and silver bearing iron-manganese ores, 706.51 ounces.

[b] Siliceous gold and silver ores contained 35,061.79 ounces; gold ores, 20,662.67 ounces; silver ores, 15,369.35 ounces; oxidized gold and silver bearing iron-manganese ores, 149.38 ounces.

[c] Siliceous gold and silver ores contained 16,425.10 ounces; gold ores, 11,974.24 ounces; silver ores, 4,172.90 ounces; oxidized gold and silver bearing iron-manganese ores, 257.84 ounces.

[d] Gold ore contained 856.32 ounces; gold and silver ore, 11,901.80 ounces; silver ore, 5,508.11 ounces; iron ore, 8.20 ounces.

[e] Gold ore contained 3,226.24 ounces; gold and silver ore, 1,534.16 ounces; silver ore, 4,488.27 ounces.

[f] Includes 663.82 ounces from gold ore, 1,130.40 ounces from gold and silver ore, and 7,328.18 ounces from silver ore.

[g] Includes 4,678.60 ounces from gold ore, 4,864.68 ounces from gold and silver ore, and 10,851.33 ounces from silver ore.

SILVER.

In value of total output silver ranks second among the metals produced in the State. In recent years the relative importance of silver has been much less and that of copper much greater than in the total period. Nearly all the metal deposits of the State, except the iron deposits, contain silver, and in many it has been the most important constituent.

The following table gives the output and value of silver from the more important districts to the close of 1917:

Silver produced in Utah to end of 1917, by districts.

District.	Fine ounces.	Value.
Park City....................	135,299,810	99,202,886
Tintic.......................	125,271,682	83,343,232
West Mountain................	48,415,824	35,665,120
Beaver County................	21,160,906	19,588,392
Ophir and Rush Valley.......	14,259,680	11,818,698
Big and Little Cottonwood..	13,140,345	13,215,039
Silver Reef..................	7,211,463	7,987,142
Fish Springs.................	2,499,603	1,627,832
American Fork................	1,887,596	2,014,647
Gold Mountain................	460,228	273,909
Other districts..............	1,578,803	1,095,717
	[a]370,985,940	276,832,614

[a] The total production of silver by districts is more than the total by years for the State, as shown in the table on pages 127–128, because the production for early years was largely estimated.

The relative importance of the several districts in the production of silver is shown graphically in figure 17.

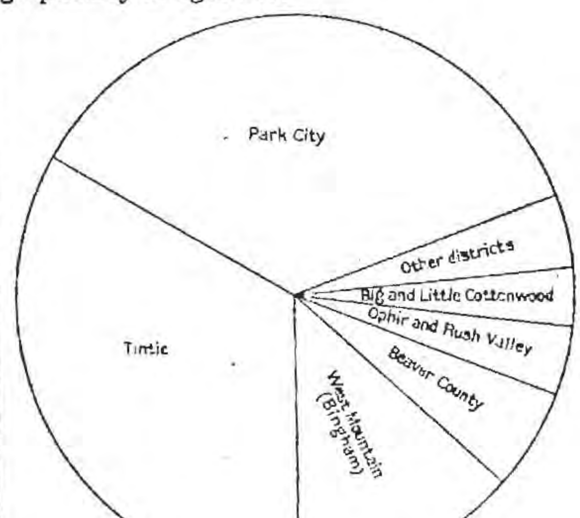


FIGURE 17.—Diagram showing relative importance of the principal districts of Utah in the production of silver, 1865–1916.

Silver production was not large till about 1870, when the discovery of the bonanzas in the Cottonwood districts caused a rapid increase. Before the exhaustion of these deposits caused serious depression the output from the Horn Silver mine in the San Francisco dis-

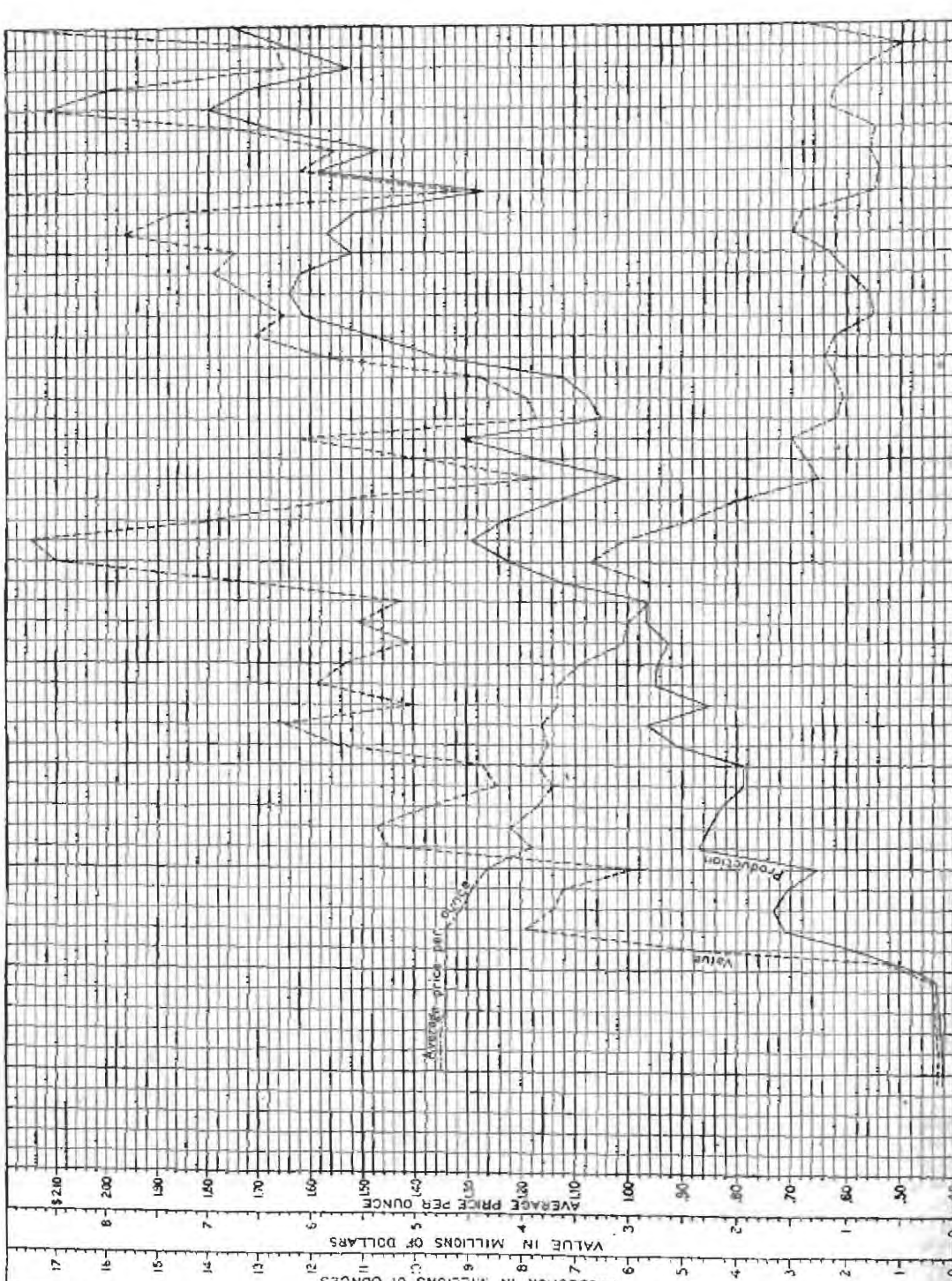


FIGURE 18.—Curves showing the annual variation in the production, value, and average price of silver in Utah, 1865-1915.

trict, from the mines of the Silver Reef district, and from lesser districts caused a further rise; and before the output from these had greatly decreased the mines of the Park City, Tintic, and Bingham districts caused a still further increase.

The yearly variation in production, value, and average price of silver is shown in figure 18. The production shows a general increase with decreases over short periods. From 1870 to about 1900 the average price decreased, but the loss was more than balanced by the increase in production, and the general upward trend in total value continued. The most notable depression was in the early nineties, when the price of silver fell rapidly from more than a dollar to about 65 cents per ounce and a notable decrease in production followed. From that time to 1917 the price did not rise much above 65 cents and most of the time was less than 60 cents. The production, however, quickly recovered, and except for a depression from about 1904 to 1910 its general trend has been upward. In recent years the recovery from copper ores has been important.

The accompanying table shows the classes of ore from which silver has been recovered and the amount recovered from each for the last 10 years:

Silver produced in Utah, 1904–1917, by kinds of ore, in fine ounces.

Year.	Placers.	Dry or siliceous ore.	Copper ore.	Lead ore.	Zinc ore.	Copper-lead-zinc ore.	Copper-lead ore.	Lead-zinc ore.	Total.
1904	....	161,209	2,386,794	1,147,565	1,176	3,296,960	5,019,274	36,468	12,049,446
1905	61	94,497	2,301,349	3,104,375	18,108	2,080,294	3,200,828	227,959	11,036,471
1906	57	111,614	2,032,205	2,688,624	10,416	2,290,437	4,254,953	162,328	11,550,634
1907	97	131,596	3,448,172	7,300,010	33,059	....	55,804	21,338	10,990,076
1908	63	163,285	2,620,680	5,570,548	1,044	....	86,132	9,580	8,451,338
1909	22	402,313	2,500,717	8,314,766	....	....	99,958	399,396	11,717,172
1910	25	548,498	2,036,909	6,423,523	6,510	....	223,108	1,228,398	10,466,971
1911	33	[a] 2,569,157	2,377,946	6,083,877	491	....	83,972	1,358,311	12,473,787
1912	46	[b] 3,486,562	2,542,381	6,212,219	14,941	....	154,091	1,425,663	13,835,903
1913	13	[c] 2,027,542	2,314,348	7,537,361	14,476	....	105,286	1,085,809	13,084,835
1914	9	[d] 1,317,364	1,726,230	7,350,213	....	....	37,216	723,884	11,154,916
1915	4	[e] 1,035,712	2,065,661	7,759,842	17,633	....	71,497	1,362,856	12,313,205
1916	2	[f] 1,153,993	2,633,402	8,118,264	2,914	....	145,439	1,199,023	13,253,037
1917	....	[g] 2,340,437	2,225,119	7,490,650	....	....	93,296	1,329,531	13,479,133

[a] Siliceous gold and silver ores contained 581,878 ounces; silver ores, 1,962,527 ounces; gold and silver bearing oxidized iron-manganese ores, 21,752 ounces.

[b] Siliceous gold and silver ores contained 1,283,317 ounces; gold ores, 2,420 ounces; silver ores, 2,108,550 ounces; gold and silver bearing oxidized iron-manganese ores, 2,206 ounces.

[c] Siliceous gold and silver ores contained 837,036 ounces; gold ores, 9,041 ounces; silver ores, 1,177,418 ounces; gold and silver bearing oxidized iron-manganese ores, 3,997 ounces.

[d] Gold ores contained 6,671 ounces; gold and silver ores, 503,487 ounces; silver ores, 795,646 ounces; iron ores, 11,560 ounces.

[e] Gold ores, contained 10,613 ounces; gold and silver ores, 114,580 ounces; silver ores, 910,519 ounces.

[f] Includes 1,550 ounces from gold ore, 38,159 ounces from gold and silver ore, and 1,114,284 ounces from silver ore.

[g] Includes 56,383 ounces from gold ore, 152,231 ounces from gold and silver ore, and 2,131,023 ounces from silver ore.

COPPER.

Copper has been produced in a small way in Utah since 1870, but for many years it did not form an important part of the metal output of the State. In the early years of mining it (like zinc) was regarded as undesirable in gold and silver ores, and at some mines—at the Horn Silver mine for instance—high-grade copper ore was thrown on the waste dumps.

The copper industry assumed real importance in the State in the late nineties with the beginning of extensive output from the limestone deposits of the Bingham district, notably from that of the Highland Boy mine. The Tintic district was already producing a few million pounds a year and there was some production from other districts. Since 1897 the yearly increase has been rapid and, with two exceptions, uninterrupted. Production from the great disseminated deposit of the Bingham district began about 1905 and has steadily and rapidly increased. A slight decrease in 1906 was mainly due to metallurgic difficulties met in starting the newly constructed Garfield smelter, and another slight decrease in 1912 was due to labor troubles in the Bingham district which closed the mines for part of the year.

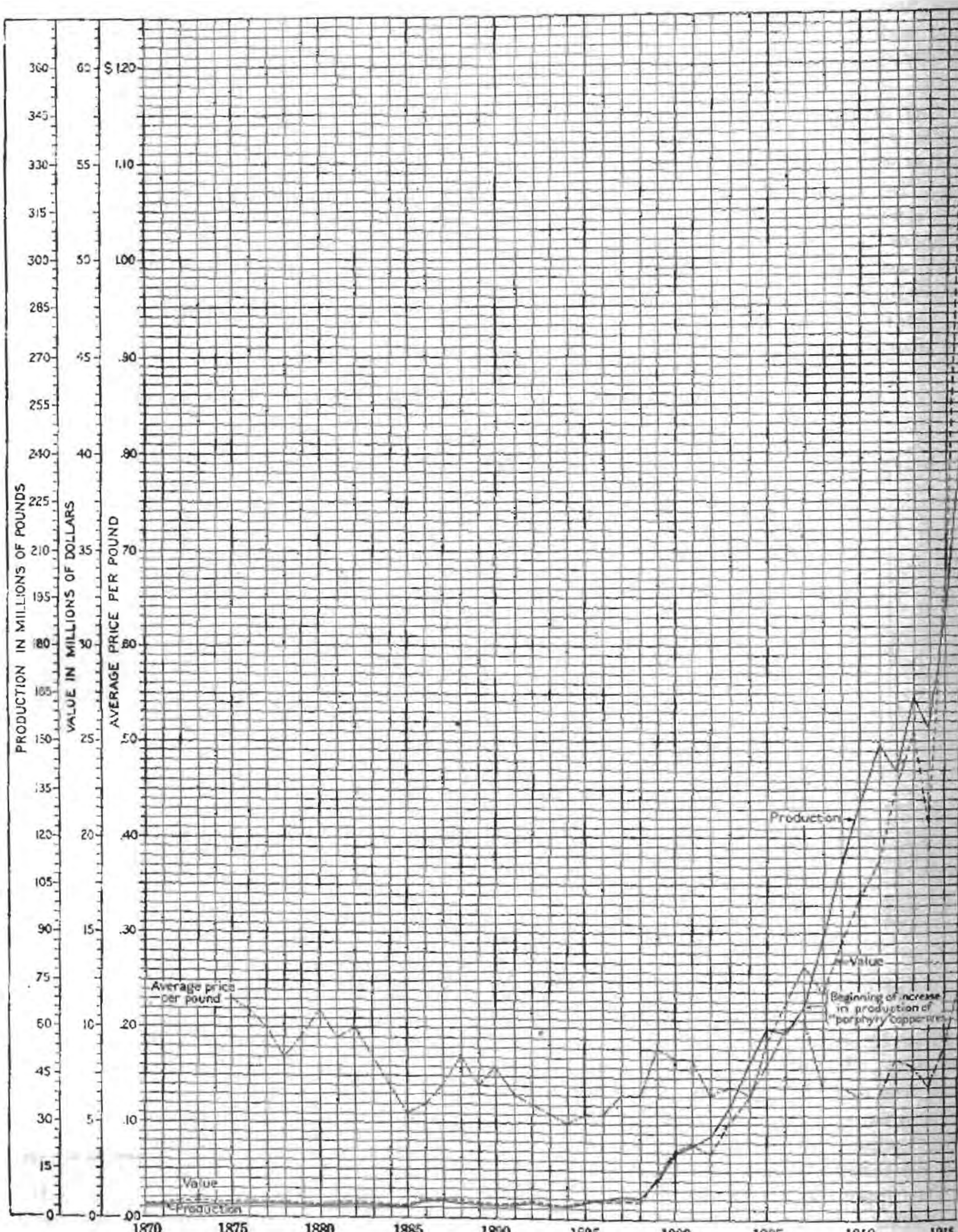


FIGURE 19.—Curves showing yearly production, value of production, and average yearly price of copper, 1870-1916.

The yearly production, the value, and the average yearly price for the period 1870–1916 are shown in figure 19.

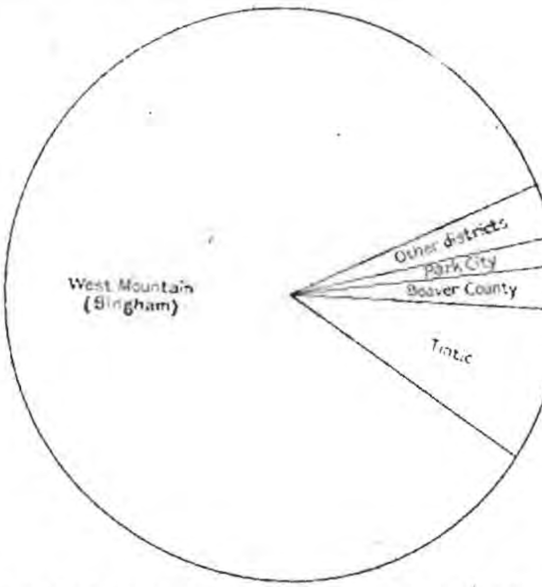


FIGURE 20.—Diagram representing the relative importance of the total output of the principal copper-producing districts to the close of 1916.

Copper is widely distributed through the State and is mined in many districts. Most of the production, however, comes from a comparatively few and the great bulk of it from one—the Bingham. The following table shows the production of the more important districts to the close of 1917:

Copper produced in Utah to end of 1917, by districts.

District.	Pounds.	Value.
Bingham (West Mountain)	1,658,636,866	$296,608,196
Tintic	171,493,635	27,552,435
Beaver County	49,638,383	8,478,593
Park City	31,028,556	4,917,960
Ophir and Rush Valley	23,026,554	4,044,373
Lucin	16,576,321	2,702,258
Tutsagubet	10,595,066	1,533,116
Big and Little Cottonwood	9,855,917	1,741,962
Carbonate	2,564,245	392,530
Other districts	3,395,468	790,449
	[a]1,976,811,011	348,761,872

[a] The total production of copper by districts is more than the total by years for the state because of estimates in early years.

The rank of the principal districts in total production is shown graphically in figure 20.

Most of the copper has been derived from copper ores, though ores chiefly valuable for other metals have yielded large amounts. The accompanying table shows its derivation by classes of ores for the period 1910–1917:

Copper produced in Utah, 1910–1917, by kinds of ore, in dry pounds.

Year.	Dry or siliceous ore.	Copper ore.	Lead ore.	Zinc ore.	Copper-lead ore.	Lead-zinc ore.	Total.
1910	1,029,927	122,306,847	2,818,234	1,628	578,250	862,186	127,597,072
1911	[a]3,259,690	139,382,161	2,885,369	478	317,359	1,115,770	146,960,827
1912	[b]3,373,103	127,712,169	4,482,998	660	355,779	1,382,776	137,307,485
1913	[c]1,466,398	152,137,467	6,627,953	....	254,773	959,371	161,445,962
1914	[d]2,020,504	142,988,221	6,147,939	....	101,794	775,544	152,034,002
1915	[e]687,998	177,784,460	7,135,528	1,250	354,162	1,707,790	187,671,188
1916	[f]1,426,917	229,960,014	7,212,843	....	559,954	1,115,494	240,275,222
1917	[g]2,579,070	235,899,850	6,256,268	....	393,079	1,545,886	246,674,153

[a] Siliceous gold and silver ores contained 2,260,868 pounds; silver ores, 983,235 pounds; gold and silver bearing oxidized iron-manganese ores, 15,587 pounds.
[b] Siliceous gold and silver ores contained 3,162,441 pounds; silver ores, 210,662 pounds.
[c] Siliceous gold and silver ores contained 1,332,520 pounds; gold ores, 1,306 pounds; silver ores, 120,720 pounds; gold and silver bearing oxidized iron-manganese ores, 12,852 pounds.
[d] Gold ores contained 12,440 pounds; gold and silver ores, 1,777,510 pounds; silver ores, 222,885 pounds, and iron ores, 7,669 pounds.
[e] Gold ores contained 2,648 pounds; gold and silver ores, 254,211 pounds; silver ores, 431,139 pounds.
[f] Includes 2,529 pounds from gold ore, 13,820 pounds from gold and silver ore, and 1,410,568 pounds from silver ore.
[g] Includes 577,971 pounds from gold ore, 1,021,380 pounds from gold and silver ore, and 979,719 pounds from silver ore.

Before 1907 the main production was from ores which were treated directly in smelters near Salt Lake and in Bingham Canyon. Since 1907, however, the proportion of copper derived from low-grade disseminated copper ores (which require concentration) has greatly increased.

The tables on page 138 show the total quantity of copper ore treated in Utah and the copper, gold, and silver recovered from it, and also the copper ore concentrated and smelted, and the copper recovered by each process for the period 1903–1917.

Total copper, gold, and silver recovered from ores in which copper constitutes the principal value, 1903–1917.

Year.	Copper ore.	Copper in ore.	Per cent of copper.	Gold in ore.	Silver in ore.[a]	Value in gold and silver per ton.
	Short tons.	*Pounds.*		*Fine ounces.*	*Fine ounces.*	
1903	517, 882	26, 622, 504	2. 57	92, 078. 00	2, 714, 165	$6. 50
1904	815, 959	40, 491, 588	2. 48	109, 968. 00	2, 572, 582	4. 61
1905	1, 248, 752	52, 548, 925	2. 10	125, 897. 00	2, 301, 349	3. 21
1906	1, 258, 884	50, 526, 081	2. 01	120, 766. 53	2, 032, 205	3. 08
1907	1, 793, 084	59, 835, 001	1. 67	158, 154. 83	3, 448, 172	3. 09
1908	2, 976, 433	83, 462, 121	1. 40	111, 086. 12	2, 620, 680	1. 24
1909	4, 216, 226	103, 871, 534	1. 23	117, 265. 85	2, 500, 717	. 88
1910	5, 417, 558	122, 306, 847	1. 13	113, 978. 49	2, 036, 909	. 64
1911	6, 121, 099	139, 382, 161	1. 14	117, 247. 94	2, 377, 946	. 60
1912	6, 670, 845	127, 712, 169	. 96	105, 720. 03	2, 542, 381	. 56
1913	9, 070, 740	152, 137, 467	. 838	100, 093. 39	2, 314, 348	. 38
1914	7, 578, 220	142, 988, 221	1. 94	97, 955. 32	1, 726, 230	. 39
1915	9, 436, 450	177, 915, 329	. 94	101, 247. 85	2, 065, 661	. 33
1916	12, 676, 152	229, 960, 014	. 90	113, 396. 52	2, 633, 402	. 32
1917	14, 121, 671	235, 899, 850	. 83	94, 844. 85	2, 225, 119	. 27

[a] These figures are arranged according to the first method of classification, 1903 to 1910, as printed in the Mineral Resources reports for those years.

Copper ores concentrated and smelted and percentage of copper recovered by each process, 1903–1917.

Year.	Ores concentrated.				Ores smelted.		
	Ores.	Concentrates produced.	Copper produced.	Per cent of copper.	Ores.	Copper produced.	Per cent of copper.
	Short tons.	*Short tons.*	*Pounds.*		*Short tons.*	*Pounds.*	
1903					517, 882	26, 622, 504	2. 57
1904	138, 372	9, 215	4, 772, 916	1. 72	677, 587	35, 718, 670	2. 64
1905	427, 598	32, 266	11, 784, 938	1. 38	821, 154	40, 763, 987	2. 45
1906	491, 816	35, 322	11, 862, 742	1. 21	767, 068	38, 663, 339	2. 52
1907	863, 606	51, 224	18, 518, 093	1. 07	908, 319	41, 317, 808	2. 27
1908	2, 331, 514	121, 046	53, 411, 303	1. 15	644, 488	29, 987, 867	2. 33
1909	3, 462, 481	147, 976	68, 173, 413	. 98	753, 278	35, 315, 285	2. 34
1910	4, 846, 429	181, 201	91, 975, 100	. 95	568, 951	30, 152, 343	2. 65
1911	5, 476, 916	228, 591	105, 951, 888	. 97	640, 729	32, 637, 950	2. 55
1912	6, 095, 728	261, 941	102, 539, 091	. 84	572, 354	25, 000, 452	2. 18
1913	8, 406, 816	382, 663	126, 364, 491	. 75	662, 892	25, 719, 652	1. 94
1914	7, 106, 594	360, 569	125, 778, 515	. 88	471, 626	17, 209, 706	1. 82
1915	8, 926, 688	427, 495	156, 436, 723	. 84	509, 762	21, 478, 606	2. 11
1916	[a]11, 943, 472	559, 840	199, 997, 786	. 84	732, 680	29, 962, 228	2. 04
1917	[b]13, 504, 435	656, 259	207, 603, 875	. 76	617, 156	28, 282, 873	2. 29

[a] Includes 175,923 tons of old tailings concentrated.

[b] Includes 207,275 tons of old tailings concentrated.

The copper industry is now the most important mining industry in the State, and as very large reserves of ore have been developed, especially in the Bingham district, it is certain to be of prime importance for many years to come.

LEAD.

Lead mining in Utah is very closely allied to silver mining, much of the lead ore containing an equal or greater value of silver, and consequently influences that have affected silver production have had an effect in lead production. The production of lead began at essentially the same time as that of silver, and the early producing districts were the same with the exception of the Silver Reef, which was entirely silver, the Lion Hill section of the Ophir district, and the early production from the Ontario vein of the Park City district.

The yearly production and value, and the average yearly price for the period 1870–1916 are shown in figure 21. Lead mining has experienced many and rather important vicissitudes, but the general trend in both quantity and value has been upward from the beginning of production to the close of 1917.

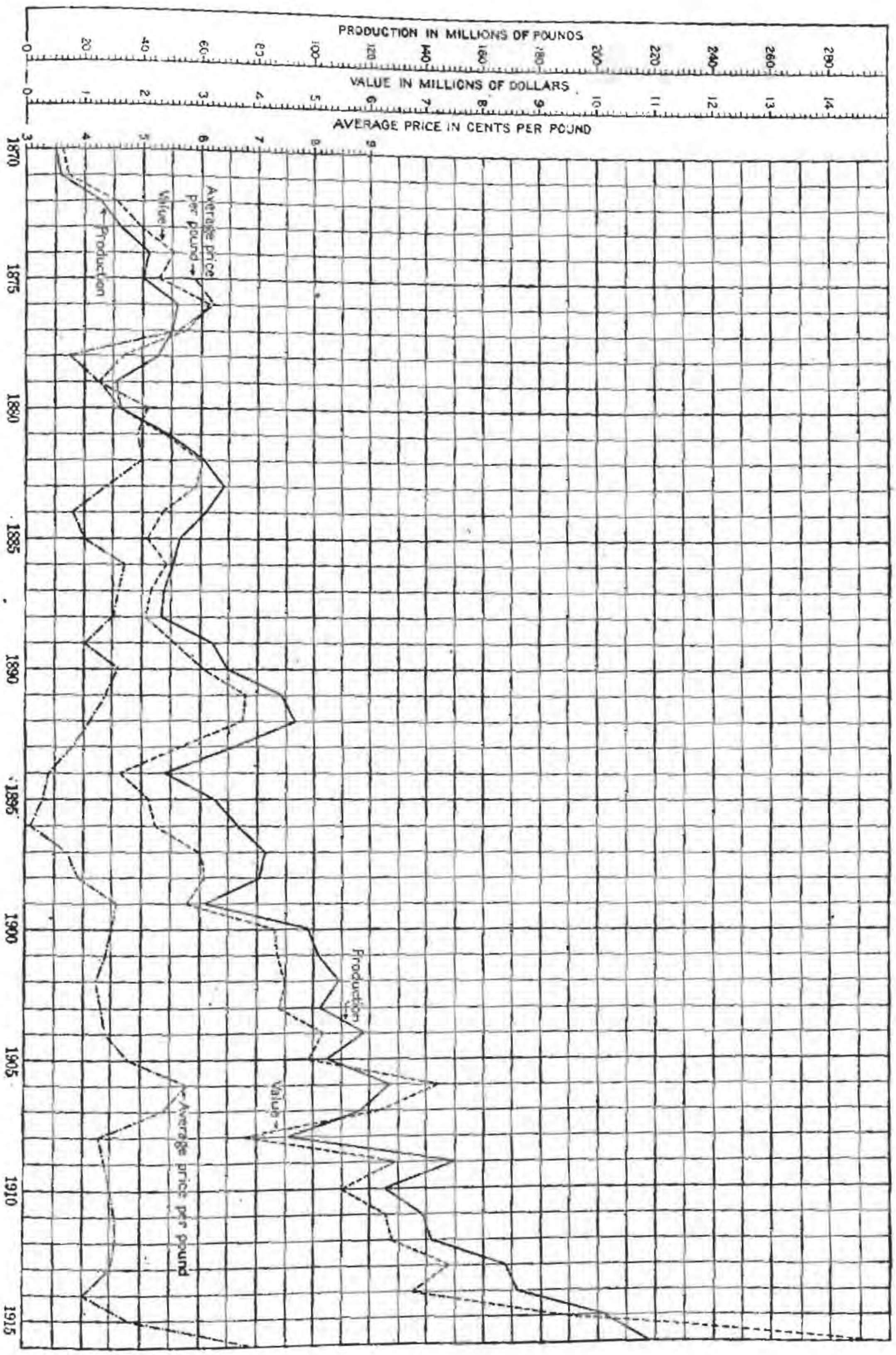


FIGURE 21.—Diagram showing annual variation in the production, value, and average price of lead in Utah, 1870-1916.

The two marked depressions (those of the middle nineties and of 1907–1909) in silver production are also notable in the lead curve, which, however, shows also some earlier rises and depressions, due to the opening or exhaustion of bonanzas, during which the silver production was kept more uniform by the output

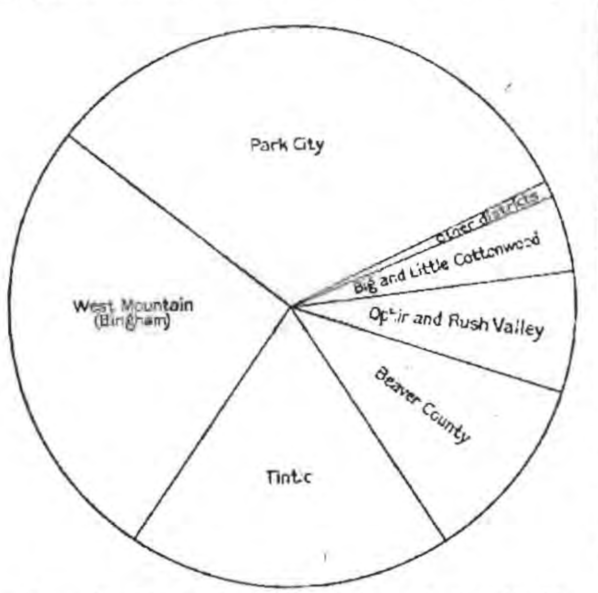


FIGURE 22.—Diagram showing the relative production of lead from the principal districts of Utah, 1870–1916.

from mines that yielded silver as their main product. The lead production of the more important districts of the State is given in the table in the next column, and is shown graphically in figure 22.

Production of lead in Utah to close of 1917, by districts.

District.	Pounds.	Value.
Park City	1,252,444,864	$56,374,893
Bingham (West Mountain)	1,058,092,538	52,429,453
Tintic	752,019,426	35,358,411
Beaver County	411,403,954	17,980,774
Ophir and Rush Valley	275,860,038	14,643,698
Big and Little Cottonwood	180,616,785	10,225,640
American Fork	28,586,796	1,574,129
Fish Springs	16,069,128	678,655
North Tintic	11,526,680	583,142
Lucin	4,749,125	294,756
Mount Nebo	1,932,683	90,780
Other districts	10,470,807	686,991
	[a] 4,003,802,824	190,921,322

[a] This total is 28,302,667 pounds more than the total by years for the State, and is accounted for in the table on p. 128. The excess in value is $2,205,476. See same excess at close of 1913.

The production of lead at the close of the period was greater than at any time during the period, and it is possible that it has not yet reached its maximum. The richer portions of many of the deposits have been mined, but there is reasonable assurance that enough ore remains in many districts to insure a large future yield. Moreover, as in other ores, improvements in mining and metallurgic methods have steadily decreased the grade of material that can be profitably mined, and it is probable that such improvements will continue and will make available much material that is not now of commercial value.

The following table shows the source of lead, by kinds of ore, for the period 1910–1917:

Lead produced in Utah, 1910–1917, by kinds of ore, in dry pounds.

Year.	Dry or siliceous ore.	Copper ore.	Lead ore.	Zinc ore.	Copper-lead ore.	Lead-zinc ore.	Total.
1910	522,046	222,127	85,396,907	221,292	4,451,792	32,510,471	123,324,635
1911	[a] 2,757,084	338,688	97,494,377	9,601	796,237	35,100,763	136,496,750
1912	[b] 1,809,989	2,194,024	106,978,033	626,503	941,532	27,761,054	140,311,135
1913	[c] 1,083,039	167,227	138,075,527	871,435	926,422	25,003,140	166,126,790
1914	[d] 814,047	2,179	146,373,700	....	272,376	23,860,835	171,323,137
1915	[e] 1,015,806	20,401	151,803,997	307,737	911,594	45,907,902	199,967,437
1916	[f] 246,028	6,540	159,260,831	230,877	1,696,276	40,049,523	201,490,075
1917	[g] 976,227	14,872	137,245,961	60,078	1,436,782	38,788,038	178,521,958

[a] Siliceous gold and silver ores contained 1,662,819 pounds; silver ores, 1,079,435 pounds; gold and silver bearing oxidized iron-manganese ores, 14,830 pounds.
[b] Siliceous gold and silver ores contained 262,817 pounds; silver ores, 1,547,172 pounds.
[c] Siliceous gold and silver ores contained 486,692 pounds; gold ores, 17,575 pounds; silver ores, 578,772 pounds.
[d] Gold ores contained 1,696 pounds; gold and silver ores, 35,476 pounds; silver ores, 763,993 pounds; and iron ore, 12,882 pounds.
[e] Gold ores contained 963 pounds; gold and silver ores, 2,305 pounds; silver ore, 1,012,548 pounds.
[f] Includes 94,635 pounds from gold and silver ore and 151,393 pounds from silver ore.
[g] All from silver ore.

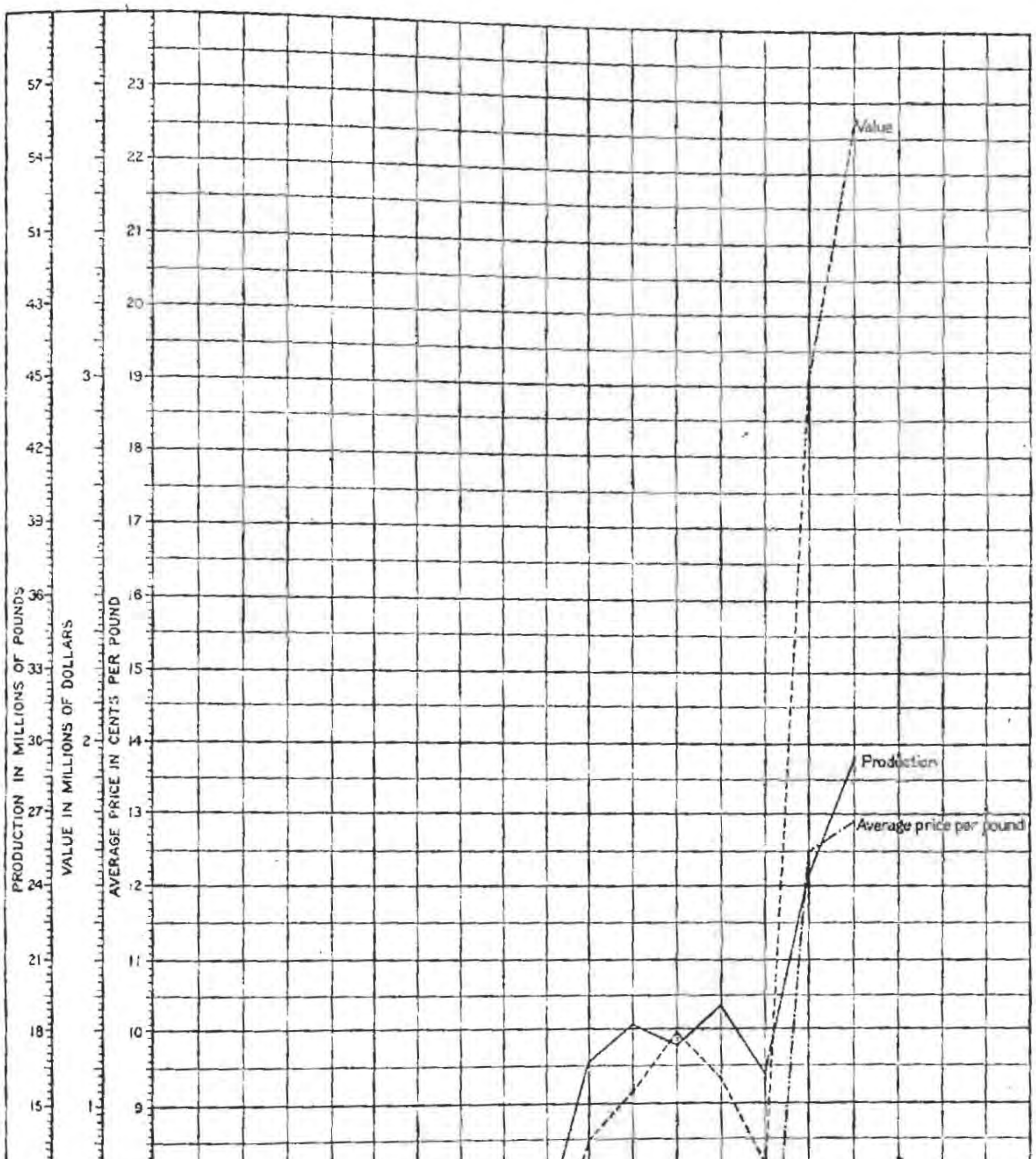


FIGURE 23.—Diagram showing the yearly production, value, and average price of zinc in Utah, 1904-1916.

ZINC.

The production of zinc in Utah began in 1904 and has rapidly increased, though as yet (1917) it has not become of great importance in comparison with the other metals. Previous to 1904 it was universally regarded as detrimental and is still so considered in many of the lead ores. Lead ores containing above a prescribed percentage of zinc are penalized by the smelters.

FIGURE 24.—Diagram showing the relative production of zinc from the principal districts of Utah, 1904-1916.

The zinc production has been derived chiefly from lead-zinc sulphide ore, in which the lead and zinc are partly separated and raised to commercial grade by milling, and from oxidized zinc ore (mainly zinc carbonate) of a grade that permits of shipment without concentration. Some sulphide ore, notably that from the Horn Silver mine, has also been shipped direct.

The annual production, value, and price of zinc from 1904 to 1916 are shown in figure 23. The total output and value from the principal districts to the close of 1917 are given in the table below, and the relative importance of the districts is shown in figure 24.

Zinc produced in Utah to end of 1917, by districts.

District.	Pounds.	Value.
Park City	66, 191, 185	$4, 951, 107
North Tintic	18, 792, 296	1, 246, 697
Beaver County	33, 507, 519	2, 577, 029
Bingham (West Mountain)	40, 052, 718	3, 678, 727
Tintic	16, 803, 653	1, 590, 790
Ophir and Rush Valley	4, 823, 331	442, 691
Other districts	11, 786, 907	1, 362, 853
	191, 957, 609	15, 849, 894

Many of the ore deposits of the State contain zinc in important amounts, and if methods of recovery can be developed will add materially to the zinc output of the State.

The accompanying table shows the production of zinc, by kinds of ore, for the period 1904–1917:

Zinc produced in Utah, 1904–1917, by kinds of ore, in dry pounds.

Year.	Copper ore.	Lead ore.	Zinc ore.	Lead-zinc ore.	Total.
1904			332, 924		332, 924
1905			5, 190, 970	1, 911, 577	7, 102, 547
1906			6, 305, 865	168, 750	6, 474, 615
1907			5, 194, 132	258, 784	5, 452, 916
1908			1, 460, 554		1, 460, 554
1909			8, 784, 779	1, 075, 999	9, 860, 778
1910			11, 271, 700	5, 095, 404	16, 367, 104
1911			1, 165, 064	16, 675, 197	17, 840, 261
1912		10, 608	5, 599, 262	11, 457, 307	17, 067, 177
1913	94, 564	34, 222	9, 539, 053	9, 189, 988	18, 857, 827
1914		16, 341	2, 984, 486	12, 988, 440	15, 989, 267
1915			9, 915, 334	14, 376, 906	24, 292, 240
1916			8, 865, 582	20, 706, 946	29, 572, 523
1917			3, 664, 962	17, 621, 909	21, 286, 871

IRON.

Metallic iron has not been produced in commercial quantities in Utah, though some attempts at smelting it were made in Iron County in early days.

Some ore chiefly valuable for its iron content has been mined and shipped to the smelters to be used as a flux for siliceous ores; and many ores chiefly valuable for other metals have brought materially higher prices from the smelters because of their iron content. The iron content of the ores has therefore been a source of considerable revenue, but as it has yielded no metallic output it has not been included in the total metal production of the State.

The following table gives the quantity and value of the iron ore mined in Utah for the years for which statistics are available. Iron was mined in other years, but no figures are to be had.

Iron ore mined in Utah.

Year.	Mined.		Marketed.	
	Long tons.	Value.	Long tons.	Value.
1885	9,720			
1892	11,101			
1908	7,348	$18,422		
1909	34,634	104,176		
1910	65,880	253,065		
1911	39,903		34,528	$123,302
1912	7,280	22,586	7,280	22,586
1913	14,690	44,628	14,690	44,628
1914, 1915	3,035		3,035	
1916	45,514		45,514	
1917	48,058		48,058	

There are large deposits of iron ore in Iron County (see p. 568), to which railway transportation can be readily extended, and at some time iron production will doubtless become important.

MANGANESE.

Some manganese ore has been mined in Utah, mainly in the Little Grande district. The known production, by years, is given in the following table:

Manganese ore produced in Utah.

	Long tons.
1901	2,500
1903	483
1904	32
1906	800
1915	85
1916	1,282
1917 (preliminary estimate)	3,580

Numerous deposits of manganese exist in the Plateau region of southeastern Utah, but most of them are remote from transportation facilities and of too low grade or of too small extent to be profitably worked at present. Some of the ores of the State contain manganese, which, like iron, serves as a flux and adds to the value of the ores. The demand for manganese ores in 1916 and 1917 resulted in a vigorous search, and ore was shipped from the Tintic, West Tintic, Little Grande, Marysvale, Ophir, Little Cottonwood, and other districts.

ALUMINUM.

No production of aluminum ores from Utah has been recorded. The alunite deposits in the Tushar Range are, however, a possible source of this metal.

ANTIMONY.

Antimony ores have been shipped at intervals since 1880, principally from the deposits on Coyote Creek, Garfield County, to an estimated total value of $100,000.

Small amounts of antimony ore were shipped from prospects near Brighton City in 1916 and 1917.

Most of the lead-silver-copper ores contain antimony and have yielded amounts far more important than that derived from antimony ores. No statistics, however, are available.

There seems little probability that the mining of antimony ores will become important, but the production of antimony from lead ores is certain to continue to yield a revenue.

ARSENIC.

Arsenic, like antimony, is present in many ores, notably those of the Tintic district, and in recent years some of it has been recovered as a by-product. No statistics are available. No promising deposits of arsenic are known, but the amount recovered as a by-product is likely to increase.

QUICKSILVER.

The following table shows the output of quicksilver by years:

Quicksilver produced in Utah, 1881–1907.

	Flasks.[1]
1881–1887	213
1903	14
1904	745
1905	1,133
1906	1,009
1907	437
	3,551

The quicksilver industry of the State is summarized by H. D. McCaskey [2] as follows:

There has been no production of quicksilver in Utah since 1907, when output of this metal as a by-product ceased at the properties of the Sacramento Gold Mining Co., in the Mercur or Camp Floyd districts in Tooele County. This company had been producing quicksilver during the period from 1903 to 1907, inclusive, prior to which there had been no reported output of metal since the Richmond Quicksilver Co. ceased operations at the Lucky Boy mine in Marysvale, Piute County, after a short run during the period 1881–1887. These two operators are the only producers in Utah of which records are at hand.

The total output of quicksilver in Utah during its productive periods from 1881 to 1887 and from 1903 to 1907, inclusive, was 3,551 flasks, valued at $139,600. Of this production 3,338 flasks, valued at $131,292, is to be credited to the Mercur district and 213 flasks, valued at $8,308, is estimated to have been the output of the Marysvale district. The entire output of the State has been from retorts.

It does not seem probable that the production of quicksilver from the State will be important.

MOLYBDENUM.

Molybdenum minerals are present in small amounts in several districts, among which are Little Cottonwood, Bingham, Lucin, Beaver Lake, Star, and Clifton. A few tons of ore has been shipped from the Little Cottonwood district.

TUNGSTEN.

Tungsten is known to occur in the Clifton district, Tooele County, the Grouse Creek Range, Box Elder County, and in the Little Cottonwood district, Salt Lake County. A few tons of scheelite ore have been shipped from the first two of these districts.

BISMUTH.

No large production of bismuth in Utah is recorded, though small shipments of bismuth ores from the Clifton and Detroit districts are reported. Bismuth is present in several districts in small amounts, however, and is collected in the bullion produced. It is relatively high in the ores of the Tintic district, from which a considerable quantity is reported to have been recovered in recent years. Each 100 tons of the blister copper produced at the Garfield smelter contains, according to Eilers,[3] an average of 6.1 pounds of bismuth.

NICKEL.

So far as known no nickel ore has been produced in the State, though small amounts of nickel are present in ores and are collected in the bullion. Thus, according to Eilers,[4] each 100 tons of blister copper produced at the Garfield smelter (largely derived from Bingham ores) contains an average of 40 pounds of nickel. Nickel is doubtless present in small amount in other districts, and if it averages as high in all the copper ores of the State as it does in those treated at Garfield its output for the year 1913 from copper ores alone would be about 30,000 pounds.

Nickel arsenate, probably annabergite, has been recognized in the ores of the Escalante mine, and nickel minerals are probably present in other ores of the State.

COBALT.

So far as known cobalt has not been produced from Utah, though, like nickel, it is probably present in small amount in the ores and may be recovered in the refining of bullion. It is known to occur in the ores of the Dolly Varden prospect in White Canyon and in the Blue Dike prospect in the same region, and it seems probable that it is present in some of the other "sandstone" deposits in the southeastern section of the State.

CHROMIUM.

So far as known chromium has not been produced from Utah. Chromium in small amount is rather widely distributed in southeastern Utah, being associated with many uranium-vanadium deposits, and is also present in garnet in the Little Cottonwood district.

SELENIUM.

Selenium occurs in small amount in many of the ore deposits of the State. It collects in the bullion and some of it is probably recovered in

[1] During 1902, 1903, and five months of 1904 the flask contained 76½ pounds net; since June 1, 1904, it has contained 75 pounds.

[2] McCaskey, H. D., Quicksilver: U. S. Geol. Survey Mineral Resources, 1911, pt. 1, p. 913, 1912.

[3] Eilers, A., Notes on the occurrence of some of the rarer metals in blister copper: Am. Inst. Min. Eng. Bull. 78, pp. 999–1000, 1913.

[4] Op. cit., pp. 999–1000.

the refining. According to Eilers[1] each 100 tons of blister copper produced at the Garfield smelter contains an average of 56 pounds of selenium.

Selenium is present in the gold-silver ores of the Gold Springs-State Line region, in the Tushar Range, in the mercury ore of the Lucky Boy mine near Marysvale, and is widely distributed in the "sandstone" deposits in the southeastern part of the State, but is nowhere sufficiently abundant to be profitably extracted, except, possibly, as a by-product in the recovery of other metals.

TELLURIUM.

Tellurium, like selenium, is present in small amount in the ores of the State. Eilers[2] states that each 100 tons of blister copper produced at the Garfield smelter contains an average of 5.54 pounds of it. Tellurium is present in the gold ores of the Gold Springs-State Line region, in deposits of the Tushar Range, and probably in the gold ores of the Mercur district. So far as known no tellurium has been recovered in the ores of the State.

PLATINUM AND PALLADIUM.

Platinum and palladium are present in the copper ores of the Bingham district and probably in the ores of other districts. They are collected in the bullion and can be recovered, with other metals, from the "muds" resulting from the electrolytic refining of the copper. According to Eilers,[3] each 100 tons of blister copper from the Garfield plant contains an average of 0.342 ounce of platinum and 1.183 ounces of palladium. Platinum in small amount is present in the placers of Colorado and Green rivers.

URANIUM, VANADIUM, AND RADIUM.

Deposits containing uranium and vanadium are rather widely distributed in southeastern Utah and have been exploited chiefly for radium, which is always associated with the uranium, though the uranium and vanadium are also recovered. The principal production of these metals has been from the region around the La Sal Mountains, the San Rafael Swell, the Henry Mountains, and near Fruita in Rabbit Valley. Uranium minerals are known to occur in the Silver Reef deposits, Washington County, near Pahriah, along the west side of Colorado River between the mouths of Green and Fremont rivers, at Circle Cliffs (Burr Flats), in White Canyon, and near Browns Park in the Uinta Mountains, and are reported from other localities.

Vanadium is present in nearly all the uranium localities and also in small amount in many of the ores of the western part of the State. It has been recognized from the Escalante mine, from the Star and Little Cottonwood districts, and from the Dyer copper mine in the Uinta Mountains, and is doubtless present in other deposits.

The first shipment of uranium-vanadium ores was made about 1904. There has been an important production of uranium-radium ores from Utah in recent years.

MINING DISTRICTS.

Most of the mining districts of Utah are organized and are described in papers filed in the office of the United States surveyor general at Salt Lake City. The districts were generally organized by the miners in order to keep accurate record of the claims located and of the assessment work done on each. One hundred dollars a year is required to be expended in development work on each unpatented claim, in default of which the claim may be relocated by other miners. In early days each district had a recorder to keep such records, but in later years the recorder was abolished and all records were transferred to the county seats.

Some districts have maintained a rather steady output for many years; others have had a large but short-lived production; and still others have never had any noteworthy production and are almost unknown to the industry.

In 1917 there were 167 organized and unorganized mining districts in Utah. The following is a nearly complete list, with the date of organization, location, and the predominating metals and minerals:

[1] Eilers, A., op. cit., pp. 999-1000.

Mining districts in Utah.

No. on Pl. I.	District.	County.	Date of organization.	Approximate location.[a]	Patents issued[a] (showing importance of district).	Predominating metals and minerals, in order of importance.
	ORGANIZED DISTRICTS.					
43	Adams (see also Hot Springs).	Salt Lake	July 3, 1873	T. 1 N., R. 1 E	3	Silver, lead.
1	Alpine	Utah		T. 4 S., R. 1 E	1	Do.
2	American Fork	do	July 21, 1870	T. 3 S., R. 3 E	86	Do.
3	Antelope	Beaver	1877	West slope of Granite Range to north of Bradshaw.		Iron, silver.
4	Argenta	Morgan	Feb. 11, 1893	T. 5 N., Rs. 2 and 3 E	3	Lead, silver, iron.
5	Ashbrook	Box Elder	July 1, 1874	T. 14 N., R. 18 W	11	Silver, gold.
6	Beaver Lake	Beaver	Aug., 1871	T. 26 S., R. 12 W	19	Copper, silver, lead.
7	Big Cottonwood	Salt Lake	July 11, 1870	T. 2 S., R. 2 E	186	Silver, lead, copper.
8	Big Indian	San Juan	June 19, 1892	T. 30 S., R. 24 E	4	Copper.
9	Black Crook, or Erickson.	Tooele	Jan. 30, 1894	T. 10 S., R. 6 W	6	Silver, gold, lead, zinc.
10	Blue Bell	do	Feb. 12, 1896	T. 10 S., R. 5 W	1	Lead, silver, gold.
11	Blue Ledge	Wasatch	May 10, 1870	T. 2 S., R. 4 E	167	Lead, silver, gold.
12	Blue Mountain (Monticello).	San Juan	Dec. 9, 1892	T. 34 S., R. 22 E		Copper, gold.
13	Bolter or Boulder	Tooele		T. 9 S., R. 3 W	1	
14	Box Elder	Box Elder	Oct. 2, 1889	T. 10 N., R. 2 W		Gold, silver, lead, copper.
15	Bradshaw	Beaver	May 1, 1875	T. 29 S., Rs. 9 and 10 W.	9	Gold, silver, lead, iron.
16	Bull Valley	Washington		28 miles south of Modena		Gold, iron.
17	Camp Floyd (Mercur).	Tooele	Apr. 16, 1870 June 24, 1894	T. 6 S., Rs. 3 and 4 W.	291	Gold, mercury, silver.
18	Carbonate	Uinta		T. 1 S., R. 21 E	12	Copper.
19	Castle Peak	Wasatch		T. 9 S., R. 17 E	12	Asphalt and bituminous rock deposits.
20	Clifton (Gold Hill)	Tooele	Oct. 18, 1869	Tps. 7 and 8 S., Rs. 17 and 18 W.	111	Copper, gold, lead.
21	Colorado River	Garfield				Gold.
22	Columbia	Tooele	1871	T. 10 S., R. 6 W	13	Silver, lead.
23	Coyote Creek	Garfield	May 3, 1879	T. 31 S., R. 1 W	9	Antimony.
24	Deseret (Desert Mountain).	Juab		T. 10 S., R. 8 W		Copper, silver.
25	Detroit (Joy) (Drum 1872).	Juab and Millard.	Aug. 27, 1879	Tps. 14 and 15 S., R. 10 W.	35	Copper, silver, gold, manganese.
26	Dugway	Tooele	Feb. 21, 1872	Tps. 9 and 10 S., R. 12 W.	59	Lead, silver.
27	Elkhorn	Wasatch	May 21, 1875	T. 2 S., R. 5 E	2	Silver.
28	Emery (Lost Springs)	Emery	Dec. 6, 1883	10 miles west of Woodside.		Copper, lead, gold, silver.
9	Erickson (see Black Crook).	Tooele				Silver, gold, lead, zinc, copper.
29	Farmington	Davis		East and southeast of Farmington.		Copper.
30	Fish Springs	Juab	Mar. 20, 1891	T. 11 S., R. 14 W., T. 10 S., R. 10 W.	26	Silver, lead.
31	Free Coinage	Tooele	May 29, 1895	T. 2 S., Rs. 6 and 7 W.	3	Clay and lime.
32	Fremont Island	Weber	Aug. 3, 1871	Island in Great Salt Lake.		Copper, gold, silver, lead, slate.
33	Gold Mountain (Kimberly).	Piute	Apr. 24, 1889	T. 27 S., R. 5 W	42	Gold, silver.
34	Gold Springs	Iron				Gold, silver.
35	Gordon	Millard and Beaver.	June 15, 1872	T. 25 S., Rs. 6 and 7 W.	21	Sulphur.

[a] Records of United States surveyor general, Salt Lake City, Utah, showing approximate number of patents on mining claims issued to the end of 1912.

Mining districts in Utah—Continued.

No. on Pl. I.	District.	County.	Date of organization.	Approximate location.	Patents issued (showing importance of district).	Predominating metals and minerals, in order of importance.
	ORGANIZED DISTRICTS—contd.					
36	Granite	Beaver	1863	T. 27 S., Rs. 8 and 9 W.		Lead, silver, copper, bismuth.
37	Granite Mountains	Tooele		T. 7 S., R. 13 W.		Silver.
38	Grantsville	do	June 15, 1875	T. 3 S., R. 7 W.	2	Lead, silver, copper.
39	Greeley (South of Camp Floyd).	do				Gold.
40	Green River (Cub Creek).	Uinta				Do.
41	Hardscrabble (Mill Creek).	Morgan		T. 2 N., R. 2 E.		Copper, iron.
42	Harrisburg (Silver Reef).	Washington	June 23, 1874	T. 41 S., R. 14 W.	23	Silver.
43	Henry	Sevier	July 6, 1883	T. 26 S., R. 4 W.	5	Copper, silver, gold.
44	Hot Springs (includes Adams).	Salt Lake	Dec., 1870	T. 1 N., Rs. 1 and 2 E., T. 1 S., Rs. 1 and 2 E.		Silver, lead, limestone for cement and lime.
45	Indian Peak	Beaver		45 miles northwest of Laud.		Lead, silver.
46	Iron Springs	Iron	1871 and Mar. 27, 1879.	T. 25 S., R. 12 W.	43	Iron.
47	Johnson Peak (Trout Creek).	Juab			1	Gold, silver, copper.
48	Juab	do		T. 13 S., R. 1 E.	1	Gypsum.
49	Lakeside	Tooele	Mar. 25, 1871	T. 2 N., R. 9 W.		Lead, silver.
50	La Sal	Grand	1897	T. 26 S., R. 24 E.	6	Copper.
51	Leamington (Oak City).	Millard	Mar. 11, 1886	Tps. 14 and 15 S., R. 3 W.		Silver, lead.
52	Lehi	Utah	Jan. 11, 1894	Tps. 5 and 7 S., R. 1 W.	3	"Onyx marble."
53	Lincoln	Beaver	Jan. 16, 1871	T. 29 S., R. 9 W.	13	Lead, silver, copper, gold, zinc.
54	Little Cottonwood (Alta).	Salt Lake	Dec. 20, 1869	Tps. 2 and 3 S., Rs. 1–3 E.	180	Silver, lead, copper, gold.
55	Little Grande	Grand		10 miles south of Little Grande, Denver & Rio Grande R. R.		Manganese.
56	Lower Placer	Salt Lake	Aug. 5, 1867	T. 3 S., R. 2 W.	2	Gold.
57	Lucin	Box Elder	1869 and Sept. 2, 1872	T. 6 N., R. 19 W.	29	Copper, gold, silver, lead.
58	McGarry	Beaver	1876	West slope of Granite Range, north of Bradshaw.		Iron, silver.
59	Marble	Summit		7 miles south of Park City.		Marble, copper, silver.
41	Mill Creek (see Hardscrabble).	Morgan				Iron, gold, silver.
60	Miners Basin	Grand	May 27, 1898	Tps. 25 and 26 S., R. 23 E.		Gold, silver, copper.
61	Mona	Juab		T. 11 S., R. 1 W.	2	Gypsum, lead, silver.
62	Monumental	San Juan	Nov. 16, 1895	Tps. 36–43 S., Rs. 6–23 E.		Oil.
63	Morgan	Morgan		T. 4 N., Rs. 2 and 3 E.		Copper.
64	Mount Baldy	Piute	Oct. 5, 1878	T. 28 S., R. 4 W.	24	Gold, potash, mercury.
65	Mount Nebo (Timmons).	Juab	Oct. 25, 1870	T. 11 S., R. 1 E.	4	Silver, lead, zinc.
	Mountain Lake (divided in 1869–70 into Big and Little Cottonwood, American Fork, and Uintah districts).	Salt Lake	1867			

Mining districts in Utah—Continued.

No. on Pl. I.	District.	County.	Date of organization.	Approximate location.	Patents issued (showing importance of district).	Predominating metals and minerals, in order of importance.
	ORGANIZED DISTRICTS—contd.					
66	Newfoundland	Box Elder	1872	T. 5 N., R. 13 W.	2	Copper, silver, bismuth.
67	Newton	Beaver	Nov. 26, 1892	Tps. 27 and 28 S., R. 6 W.	6	Gold, silver.
36	North Granite (see also Granite).	do	1865	North of Granite district.		Lead, low-grade ore.
98	North Star (see also Star).	do	Nov. 11, 1871	T. 28 S., R. 11 W.	26	Silver, gold, copper, lead, zinc.
68	North Tintic (Oasis in 1873 and Caledonia in 1875).	Tooele and Utah	1879 and May 4, 1891	T. 9 S., R. 2 W.	38	Zinc, lead, silver.
68	Oasis (Caledonia)	Tooele	1875–1879			
69	Ohio (Marysvale)	Piute	Feb., 1868 Aug., 1872	Tps. 27 and 28 S., R. 4 W.	46	Gold, silver, lead.
70	Ophir	Tooele	Aug. 6, 1870	T. 5 S., R. 4 W.	154	Silver, lead, zinc.
71	Osceola (south of Camp Floyd).	do				
72	Paradise (La Plata).	Cache	May 26, 1881	T. 9 N., R. 2 E.	6	Lead, silver.
73	Park Valley	Box Elder		13 miles northwest of Kelton.	16	Gold, silver, copper, lead.
74	Payson	Utah	1871–72	Western foothills of Wasatch Range.		Silver (low grade).
75	Pine Grove	Beaver	1873	Tps. 28 and 29 S., R. 16 W.	4	Gold, silver.
76	Pinto Iron (silver belt).	Iron	May 26, 1868	T. 36 S., R. 14 W.	57	Iron, lead, silver.
77	Promontory	Box Elder		Lakeside, Saline, Southern Pacific R. R.		Zinc, lead, copper, silver.
78	Provo	Utah	Mar. 11, 1871	T. 6 S., R. 3 E.	3	Lead, silver.
79	Pruess (Newhouse)	Beaver	Sept. 4, 1880	T. 26 S., R. 13 W.	8	Copper, gold, silver.
80	Richardson	Grand		27 miles south of Cisco, Denver & Rio Grande R. R.		Uranium, vanadium.
81	Richmond	Cache		T. 13 N., R. 2 E.	1	Copper.
82	Rhodes Plateau (Woodland).	Wasatch				Iron and manganese.
83	Rocky	Beaver	Mar. 27, 1872	T. 27 S., R. 11 W.	6	Copper, gold, silver, iron.
84	Rosebud	Box Elder	1873	10 miles northwest of Terrace.		Lead, silver, gold.
85	Rush Valley (Stockton).	Tooele	June 12, 1864	T. 4 S., R. 4 W	137	Silver.
86	Salina Creek	Sevier		4 miles east of Salina		Lead, zinc.
87	San Francisco (Frisco).	Beaver	Aug. 12, 1871	T. 27 S., R. 13 W.	74	Lead, copper, silver, gold, zinc.
88	San Rafael	Emery		18 miles southwest of Green River, Denver & Rio Grande R. R.		Uranium, vanadium, copper.
89	Santa Clara	Washington	1880	10 miles west of St. George.		Silver.
90	Santaquin	Utah	1871	T. 10 S., R. 2 E.	3	Silver, lead.
91	Saw Back	Millard	1872	West of Sevier Lake		
92	Sierra Madre	Weber	Feb. 12, 1902	Tps. 7–8 N., R. 1 W. Tps. 7–8 N., R. 1 E.	2	Copper, silver.
93	Silver Islet	Tooele	1872			Lead, silver, copper.
94	Silver Lake	Utah	Jan. 28, 1871	T. 4 S., R. 2 W.	5	Lead, silver.
95	Snake Creek (formerly White Pine, Howland).	Wasatch	May 10, 1870	Tps. 2 and 3 S., Rs. 3 and 4 E.	191	Silver, lead.
96a	Spanish Fork (Cook)	Utah	1870–71	Western flank Wasatch Range south of Provo district.		Lead, silver.

Mining districts in Utah—Continued.

No. on Pl. I.	District.	County.	Date of organization.	Approximate location.	Patents issued (showing importance of district).	Predominating metals and minerals, in order of importance.
	ORGANIZED DISTRICTS—contd.					
97	Spring Creek	Juab	June 4, 1891	Tps. 11 and 12 S., R. 19 W	22	Gold, silver.
98	Star (known as South Star).	Beaver	July 8, 1870	T. 28 S., R. 12 W	35	Lead, silver, copper, gold, zinc.
99	Smelter	Salt Lake		South of Salt Lake City		
100	Stateline	Iron	1896	Tps. 32-34 S., Rs. 19 and 20 W.	21	Gold, silver.
101	Sterling	Beaver	Feb., 1880	Wahwah Range west of Frisco.		Iron.
102	Sulphur	do		T. 29 S., R. 14 W	1	Sulphur.
38	Third Term (see also Grantsville).	Tooele			1	Lead, silver, copper.
103	Tidewell & Rideout.	Carbon	Feb. 21, 1890	T. 13 S., R. 13 E	1	Asphalt.
65	Timmons (see also Mount Nebo).					
104	Tintic	Juab and Utah	Dec. 13, 1869	Tps. 9-11 S., Rs. 2 and 3 W.	873	Gold, silver, lead, zinc.
105	Tooele	Tooele	1870	T. 3 S., R. 3 W	26	Gold, silver, copper, lead.
106	Tutsagubet	Washington	June 2, 1883	T. 43 S., R. 17 W	3	Copper, lead.
107	Uintah (Park City)	Summit	July 8, 1871	Tps. 1 and 2 S., Rs. 3 and 4 E.	845	Silver, lead, zinc, copper.
108	Utah (eastern part of Tintic district).	Utah		T. 10 S., R. 2 W	3	Silver, copper, lead.
	Wasatch (see also Mountain Lake).	Salt Lake	July 20, 1864			Granite.
109	Washington	Beaver	1879	T. 29 S., R. 19 W	8	Silver, copper lead, gold.
110	Weber (formerly Junction 1860).	Weber	Feb., 1878	T. 6 N., R. 1 E.; T. 6 N., R. 1 W.	1	Silver, lead, gold.
111	West Mountain (Bingham).	Salt Lake	Dec. 17, 1863	T. 3 S., R. 3 W	837	Copper, lead, silver, gold, zinc.
112	West Tintic	Juab	1870, reorganized Nov. 29, 1892	T. 11 S., R. 5 W	5	Silver, lead.
113	Wheeler Desert	Grand	June 24, 1901	T. 23 S., R. 17 E	5	
114	White Canyon (Eite)	Garfield	1892	T. 31 S., R. 10 E.; T. 36 S., R. 13 E.	9	Gold, copper, uranium.
	White River	Wasatch and Utah.	Sept., 1879	Northeast of Clear Creek station, Denver & Rio Grande R. R.		Hydrocarbons.
115	Willard	Box Elder	July 30, 1870	T. 8 N., R. 2 W	6	Iron, antimony.
116	Willow Springs	Tooele	May 21, 1891	T. 10 S., R. 18 W.; T. 9 S., R. 18 W.	1	Silver, lead.
50	Wilson Mesa (see also La Sal).	Grand		49 miles southeast of Thompsons, Denver & Rio Grande R. R.		Gold.
	UNORGANIZED DISTRICTS.					
		Box Elder		T. 13 N., Rs. 14 and 15 W.; T. 4 N., R. 7 W.; T. 6 N., R. 9 W.		
		Beaver		T. 26 S., R. 9 W	2	
		Davis		Tps. 2 and 3 N., R. 3 W.		
		Emery		T. 18 S., R., 13 E	1	Copper.
		Grand		T. 22 S., R. 18 E		
		Juab		T. 9 S., R. 3 W	4	
		Millard		T. 16 S., R. 12 W	1	
		Rich (unorg.)		Tps. 11 and 12 N., R. 8 E	2	
		Salt Lake		T. 1 S., R. 3 W	1	
		Sevier		T. 21 S., R. 1 E	1	Lead.
		Summit		T. 2 S., R. 6 E	1	
		San Pete		T. 16 S., R. 3 E	1	Stone.

Mining districts in Utah—Continued.

No. on Pl. I.	District.	County.	Date of organization.	Approximate location.	Patents issued (showing importance of district).	Predominating metals and minerals, in order of importance.
	UNORGANIZED DISTRICTS—contd.					
	....	Tooele..........	....	T. 3 S., R. 3 W......... T. 9 S., R. 3 W......... T. 1 S., R. 11 W......... T. 1 N., R. 11 W......... Tps. 7 and 8 S., R. 3 W..	36	Copper, gold, silver.
	(Wild Cat Mountains.)	.....do..........	....	T. 4 S., Rs. 12 and 13 W.	....	Silver, copper, and fluorite.
	....	Uinta..........	....	Uintah special base and meridian. T. 2 S., R. 2 E.......... Tps. 1-3 S., R. 1 E...... T. 4 S., Rs. 3-8 W....... T. 4 S., Rs. 1-3 E....... T. 5 S., Rs. 5-7 W....... T. 6 S., Rs. 5-7 W....... Salt Lake base and meridian. T. 9 S., R. 25 E......... T. 9 S., R. 24 E......... T. 12 S. R. 25 E......... T. 11 S., R. 24 E......... T. 10 S., R. 24 E.........	68	Hydrocarbons, copper, gold, silver, building stone.
	....	Utah..........	....	T. 9 S., R. 4 E.......... T. 9 S., R. 7 E.......... T. 10 S., R. 4 E......... T. 10 S., R. 5 E......... T. 10 S., R. 2 W......... T. 11 S., R. 8 E......... T. 11 S., R. 9 E.........	24	Hydrocarbons, limestone, lithograph rock.
	....	Wasatch..........	....	T. 2 S., R. 9 E.......... T. 10 S., R. 8 E......... T. 11 S., R. 11 E.........	21	Building stone.
	....	Washington.....	....	T. 38 S., R. 17 W.........	2	Copper.

ORE DEPOSITS.

CLASSIFICATION.

The ore deposits of the State may be classified according to age, form, or genesis. For the purpose of comparison of the various deposits, which is one of the main objects of the general discussion, a genetic classification has numerous advantages and is used in this paper as the basis for the main divisions, further subdivision being made on the basis of the metal content. In the discussion of individual districts use is made of such other characteristic features as seem best to bring out the relations in the particular area.

The classification adopted is based on that proposed by Lindgren.[1]

[1] Lindgren, Waldemar, Mineral deposits, p. 188, New York, McGraw-Hill Book Co., 1913.

ORIGIN.

DEPOSITS DUE TO MECHANICAL CONCENTRATION.

GOLD PLACERS.

Gold placers within the State are neither numerous nor of great importance. The only ones that have contributed largely to the gold output are those of the Bingham district, though others have been worked in the La Sal Mountains, the Henry Mountains, near Marysvale, and on Colorado River and its tributaries, Green, Grand, and San Juan rivers. The total output probably has not exceeded $1,800,000 in value.

The deposits in the Bingham district are in the bench gravels of Bingham Canyon and its tributaries and in stream gravels that have been largely derived from the reworking of the bench deposits.

The occurrence of the gold is typical. In general, the richest deposits are near bedrock though some are in pay streaks higher in the gravels. The gold is rather coarse, especially near the heads of the canyons, and finer farther downstream. The canyons drain a mineralized area and there can be little doubt that the gold was freed and concentrated through the weathering and erosion of the neighboring rocks. (See also p. 361.)

The deposits in the La Sal Mountains occur on a high bench or mesa that marks the level at which the mountain streams flowed out on a plain surrounding the mountains at an earlier period in the physiographic development of the region. Later an uplift of the region caused the streams to cut canyons in the mesas surrounding the mountains. The weathering of the material in these deposits has not been very complete and the short distance that the gold has been transported has not entirely freed it from gangue minerals, so that its recovery is difficult. The associated rocks and minerals indicate that the gold has been derived from the gold-copper veins of the La Sal Mountains.

The deposits of the Henry Mountains are apparently in general similar to those of the La Sal Mountains, though gold has been recovered from stream beds as well as from gravels on benches and mesas. As in the La Sal Mountains the gold has been derived from the neighboring gold-copper veins.

The deposits near Marysvale are at the base of the range on a bench that marks the level at which the streams once flowed. The principal deposits are near the mouth of Bullion Canyon, and there is little doubt that the gold was derived from gold-bearing veins cut by the stream flowing therein.

A little gold has been recovered from placers below the outcrop of the Annie Laurie vein in the Mount Baldy district. Gold is also reported in the gravels on the west side of the Tushar Range, but none has been produced.

Some of the gold-bearing districts, notably the Mercur and the Tintic, contain no placer deposits. In the Mercur, and possibly in the Tintic, this is attributable to the finely divided condition of the gold, which does not favor its concentration in placers. In the Tintic district the small amount of the deposits that have been removed by erosion may also be a factor.

Numerous river placers, both bench and stream, occur along Colorado River and its principal tributaries. The gold is very finely divided and shows little tendency to form rich pay streaks. A little platinum has been found with the gold. The deposits have been worked to some extent at numerous localities, but recovery of the fine gold has everywhere been difficult and the operations have not been very successful. Dredging has been tried on Green and Colorado rivers but has not proved successful.

The gold has possibly been derived from the sedimentary rocks of the region, which are known to contain the metal in small amounts, or from gold-bearing deposits near the headwaters of the streams. The bench placers were formed in the river channels during earlier stages in the physiographic development of the region, and modern stream placers are now being formed by a concentration of the gold brought into the rivers by the weathering and erosion of the rocks of the adjacent areas and of the earlier deposits. (See also p. 640.)

The black sands that accompany the gold might be of commercial value under favorable conditions. These black sands are composed mainly of magnetite with lesser amounts of ilmenite and chromite and of heavy silicates, such as garnet and zircon. In some placers they are said to constitute 7 to 8 per cent of the gold-bearing material, and to contain, after amalgamation treatment, as much as $3 to $4 in gold to the ton, but they doubtless average much less. If such material could be shipped cheaply to the smelters, the value of its iron for fluxing might pay a large part of the cost, leaving the gold as a profit. Under present transportation conditions, however, the black sands probably have no value.

GOLD IN CONSOLIDATED SEDIMENTS.

The Triassic and Jurassic sandstones and shales of the plateau region contain small amounts of gold over large areas. Lawson estimates that at Paria, where they have been carefully and rather extensively sampled, each cubic yard of rock contains about 5 cents worth of gold. Similar quantities are probably present in the rocks over many hundreds of square miles. The gold is very finely divided and, it is said, can not be collected by

panning. Unsuccessful attempts to exploit deposits of this character have been made at Paria and on lower San Juan River.

The gold content of the rocks was doubtless derived from the same source as the other materials making up the sediments, possibly from the area to the north and east, where the Triassic and Jurassic formations overlap the pre-Cambrian rocks. Many and perhaps most sedimentary rocks contain traces of gold, but the content of these rocks is above the normal. The wide distribution of the auriferous sediments indicates that the rocks from which they were derived must have contained rather abundant metal deposits. (See also p. 636.)

DEPOSITS DUE TO CHEMICAL CONCENTRATION OF MATERIAL ORIGINALLY DISSEMINATED IN THE ROCK.

The deposits in the sandstones of the Plateau region show great differences in their metal content and some differences in their geologic occurrence, but they possess so many features in common that practically all geologists and engineers who have examined them consider them to be of one type. There is, however, no such agreement as to the source of their metals, which are believed by some to have been introduced from outside sources and by others to have been deposited with the rocks in essentially their present concentration. The author believes that they were produced by the concentration of metals originally deposited with the sediments.

DISTRIBUTION OF THE DEPOSITS.

Geologically the deposits of this type range in age from upper Carboniferous to Tertiary. Geographically they are widely distributed, but those of commercial importance that have been thus far developed lie in a few rather well-defined regions, namely, the areas around the La Sal Mountains, the San Rafael Swell, the Henry Mountains, and the vicinity of Leeds.

On the basis of metal content the deposits may be separated into four principal groups—silver deposits, copper deposits, uranium-vanadium deposits, and manganese deposits, a deposit rich in one of these metals or group of metals being usually deficient in the others. For example, the deposits of the Silver Reef district are rich in silver, but contain relatively little copper, and, so far as known, relatively little uranium and vanadium. Most commercial deposits of copper contain little or no uranium and vanadium and little silver, though a few of them are rather rich in silver. Most deposits that are particularly rich in uranium and vanadium contain little copper and commonly little silver, though many of them contain chromium and some contain it in abundance. Manganese in small amount is rather generally present, but where it is sufficiently concentrated to form an ore the other metals are commonly absent. Of the minor metals selenium is rather widely distributed in deposits of this type, but thus far has not been found in commercial quantities. Cobalt is present in the Dolly Varden mine in White Canyon and perhaps in other deposits, lead occurs at Miners Mountain, and iron is associated with all the deposits.

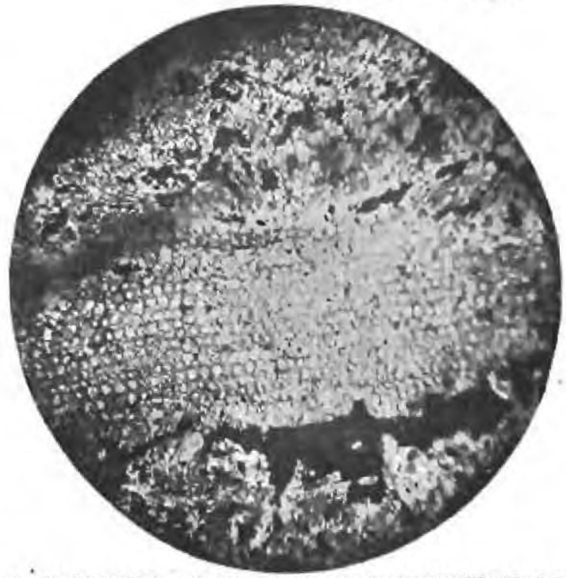
The copper deposits are most widely distributed geographically. They are scattered over the Plateau region from the southern border of the State north to the line of the Denver & Rio Grande Railroad and are found still farther north in the Uinta Basin, most extensively in the vicinity of Ouray. Similar deposits are present over a wide area in Arizona, New Mexico, Colorado, Texas, and Oklahoma.

Important silver deposits are far more restricted in distribution, the Silver Reef district being the only large producer of silver ores of this type in Utah, though similar ores occur in Colorado and copper ores containing important amounts of silver have been extracted from deposits north of the La Sal Mountains, and especially from the Cashin mine in western Colorado, a few miles east of the Utah-Colorado State line.

The uranium-vanadium deposits are also far more restricted geographically than the copper deposits, the more important deposits being apparently confined to the Plateau area of eastern Utah and western Colorado. In Utah the larger known deposits of this type lie south of the Denver & Rio Grande Railroad and extend from the San Rafael Swell eastward to Colorado and southward to the Henry Mountains. Uranium and vanadium minerals have been found outside of this area, at Silver Reef and near Paria at Burr Flats, in Rabbit Valley,

A. PHOTOMICROGRAPH OF CARBONIZED VEGETABLE MATERIAL FROM THE DOLLY VARDEN MINE, SHOWING CELLULAR STRUCTURE.

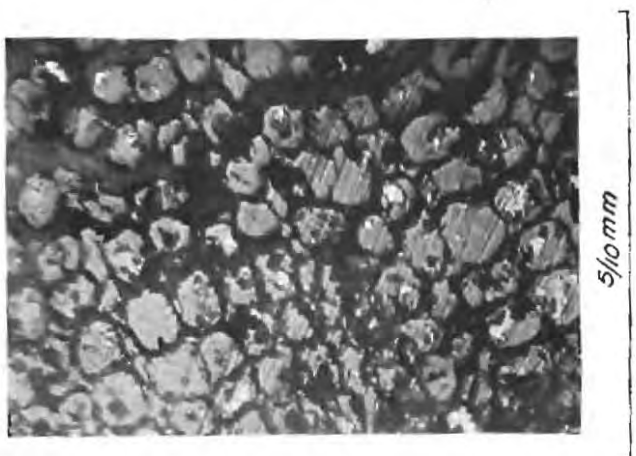
Enlarged 130 diameters.



B. PHOTOMICROGRAPH OF VEGETABLE MATERIAL REPLACED BY SULPHIDE FROM THE BLUE DIKE MINE, SHOWING CELLULAR STRUCTURE.

Light areas, chalcopyrite; dark interstitial areas, chalcocite. Enlarged 50 diameters.

C. REPLACEMENT OF VEGETABLE MATTER BY IRON SULPHIDE (PYRITES AND MARCASITE?) LARGELY ALTERED TO LIMONITE, WHICH STILL RETAINS CELLULAR STRUCTURE, FROM CIRCLE CLIFFS.



D. ENLARGEMENT OF C, SHOWING REMNANTS OF IRON SULPHIDE.

E. PHOTOMICROGRAPH SHOWING LONGITUDINAL SECTION OF CELLULAR STRUCTURE.

F. PHOTOMICROGRAPH SHOWING CROSS SECTION OF CELLULAR STRUCTURE.

and in other localities, but so far have not been commercially exploited.

Manganese has been extracted on a commercial scale at only a few localities, mainly in the Little Grande district, about 25 miles southeast of Green River, and at several localities east of this district.

Geologically as well as geographically copper is the most widely distributed of the metals, occurring in rock from upper Carboniferous to Tertiary in age. The deposits in the Uinta Basin are, so far as known to the writer, the only occurrences in the West of deposits of this type in rocks as late as Tertiary.

The only large deposits in which silver is the important metallic constituent are those in the Triassic rocks of the Silver Reef district. Somewhat similar deposits at Eagle, Colo., are probably in Jurassic sandstones. In the Cashin mine in western Colorado rich copper-silver ores occur in a fissure in Jurassic and Triassic rocks and the ores are probably in both.

The uranium and vanadium deposits thus far developed are in the Upper Jurassic (?) (McElmo formation) and the Triassic, as at Temple Rock on the San Rafael Swell, near Fruita, at Richardson, north of the La Sal Mountains, and in White Canyon.

The only manganese deposits from which ore has been shipped are in Jurassic (?) rocks of the McElmo formation. Manganese is present, however, in many deposits and at several horizons.

CHARACTER OF THE DEPOSITS.

Deposits of this type are characteristically lenticular bodies in sandstone, frequently associated with vegetable matter. They may vary in extent from those confined to a single tree trunk to the impregnation of the strata with mineral over a large area.

The deposits of this type within the State have several characteristics in common, regardless of their geographical distribution, the age of their inclosing rock, and their metal content. Nearly all of them occur in sandstones, most of which are rather coarse and many of which contain lenses of conglomerate. The sandstones are almost invariably light gray in color, though the series of rocks of which they form a part is prevailingly red. Some of the deposits, as those of the Silver Reef district, occur in small lenses of shale in the sandstone that have been converted into ore through the deposition of minerals along planes of movement.

Plant remains are characteristically associated with the deposits, and in many places are abundant. They are commonly in part silicified and in part carbonized. The ore minerals are associated with the carbonized material and have replaced the calcareous or clayey cementing material of the rock and also some of the quartz grains. Silicified fossil plants contain little, if any, metal, but carbonized plants may contain much.

Sulphide minerals have been found by the writer in few of the Utah deposits, and the material collected by him is not suitable for an adequate study of the original mineralization. Sulphides replace both the vegetable material, as in the Blue Dike mine, White Canyon, and the cement of the rock. In the Blue Dike material the earliest sulphides represented are pyrite and chalcopyrite, which have been partly altered to chalcocite and covellite.

The cellular structure of the vegetable material is well preserved (see Pl. XIV) in these specimens as well as in those from other localities. Fath [1] has described the preservation of the cellular structure of wood during its replacement by iron sulphide in the "Red Beds" in Oklahoma and the subsequent replacement of the iron sulphide by chalcocite.

Hess [2] has pointed out that the cellular structure of the wood is preserved in specimens of copper ore replacing vegetable matter examined by him, and has concluded that the replacement occurred before the wood was carbonized.

Carbonized material in which the cellular structure is preserved, and which is known to be similar to that replaced by sulphides, was not obtained. Carbonized material from the Dolly Varden mine, near the Blue Dike prospect, has the cellular structure preserved with no indication of flattening of the cells. The cells, however, are much smaller than those replaced by copper in the Blue Dike material. (See Pl. XIV.) David White believes that the cells in the carbonized material have

[1] Fath, A. E., Copper deposits of the red beds of southwestern Oklahoma: Econ. Geology, vol. 10, pp. 140-150, 1915.

[2] Hess, F. L., A hypothesis for the origin of the carnotites of Colorado and Utah: Econ. Geology, vol. 9, p. 681, 1914.

shrunk materially during carbonization. If this represents the same type of material as that replaced by the sulphide, the replacement evidently occurred before the carbonized material reached its present condition.

The alteration of the wood in shale beds differs markedly from that in the sandstone. In several localities in the Circle Cliffs (Burr Flats) region, and also in Rabbit Valley, the shale beds beneath the "tree-bearing" sandstones contain what appear to be upright stumps, though it was not shown that they have roots in place. These stumps, instead of being converted into cherty material as are those in the overlying sandstones, consist of a friable mass of silica, gypsum, carbonized wood, and iron sulphide with its oxidation products, basic sulphate, and limonite. The iron sulphide has replaced the wood and preserved the cellular structure, which is brought out prominently on the alteration to limonite. (See Pl. XIV.) So far as the writer is aware, no metallic minerals other than iron have been found in petrified wood in the shale, though the yellow basic iron sulphate jarosite, which in many places is rather abundant, has frequently been mistaken for carnotite.

Nodular masses of iron sulphide partly replaced by copper sulphide were observed in the ore from the Big Indian mine. (See Pl. L, *B*, p. 614.)

In the Silver Reef district the primary silver mineral was probably the sulphide argentite, though it has been suggested (p. 593) that this may be secondary. In the oxidized zone the silver is present as the chloride cerargyrite and as native silver.

The form in which the uranium and vanadium minerals were originally present is as yet uncertain. At present much of the uranium is in the form of carnotite, though in some deposits other uranium minerals are more important. Hewettite and carnotite are the common vanadium compounds, but others are present.

RELATION OF DEPOSITS TO GEOLOGIC STRUCTURE.

The relation of the more important deposits to the geologic structure is very apparent, and careful study of the lesser deposits will probably reveal similar though less obvious relations.

The Silver Reef deposits,[1] which commercially are by far the most important of this type yet found in this country, are near the crest of a prominent anticline. Where the ore-bearing strata have been removed for several hundred feet below the crest of the anticline the remaining portion does not contain ore. (See Pls. XLVI, in pocket, and XLVII, p. 586.)

The copper deposits in Salt Wash, northwest of the La Sal Mountains, show a similar relation to the Salt Wash anticline; and the deposits of Big Indian Valley are associated with fissures and are in the south limb of an anticline. The Cashin deposit in western Colorado is distinctly associated with a fissure. In other copper deposits the relation to structure is not superficially apparent; for example, the deposits in the Tertiary sandstones near Ouray.

Reports on the uranium and vanadium deposits of Utah and Colorado do not call attention to any close relation between them and the geologic structure, though Gale[2] states that the deposits in Routt County, Colo., are "very evidently mere crusts or coatings or superficial impregnations in sheared, brecciated, and jointed zones in the rock mass. The zones of brecciation evidently mark the path of the mineralizing solutions." Gale further notes that the deposits are "on the southern flank of a domal flexure or uplift." Ransome[3] has called attention to their association with minor structures believed to be of recent origin.

It may be pointed out that all the districts in which important deposits have thus far been discovered are associated with important structural features. Thus, the largest field in Colorado and adjacent parts of Utah is within the great series of northwest-southeast folds that center in the La Sal Mountains. From the relations of the Silver Reef and Salt Wash deposits one might expect a relation between the Paradox anticline and the deposits of that region, between the Gypsum Valley anticline and the deposits of that region, between the Salt Wash anticline (or the associated faults) and the Richardson deposits, and between the Dome Plateau anticline and the deposits near Thomp-

[1] The writer places the Silver Reef deposits in this class, though he realizes (see p. 593) that they may have had a different origin.

[2] Gale, H. S., Carnotite and associated minerals in western Routt County, Colo.: U. S. Geol. Survey Bull. 340, p. 262, 1907.

[3] Hillebrand, W. F., and Ransome, F. L., On carnotite and associated vanadiferous minerals in western Colorado: U. S. Geol. Survey Bull. 262, pp. 14-15, 1905.

son. Likewise the deposits along the San Rafael Swell are apparently associated with the sharp monoclinal fold along the eastern side of that great dome; and the deposits of the Henry Mountains region are apparently associated with the domical uplift of those mountains.

GENESIS OF THE ORES.

CONFLICTING THEORIES.

The genesis of the deposits in sandstone is a subject on which geologists have long differed, perhaps because the deposits at different localities have had different modes of origin—although they have differed quite as much regarding the origin of individual deposits as regarding that of the class as a whole.

The first deposit of commercial importance developed in the sandstones in Utah was that of Silver Reef district, and very soon a rather heated discussion arose concerning its genesis. Two fundamentally different ideas were advanced—first, that the silver and accompanying copper, vanadium, uranium, and selenium minerals were contemporaneous in origin with the sedimentary rocks in which they are now found, having been deposited from a body of mineral-bearing waters, in which the sediments accumulated, by the reducing action of decaying vegetation; second, that the metallic minerals were later than the sandstones and were deposited by mineralizing solutions whose circulation was connected with the igneous activity of the region. The first explanation was advanced by Newberry, and the second by Rolker, Maynard, Rothwell, and Cozin. More recently a third mode of origin has been suggested by Lindgren,[1] who sought to explain similar copper deposits by the "concentration of minute traces of copper in certain strata or in fissures, by circulating atmospheric waters charged with chloride and sulphate." Lindgren thought that the copper had been deposited in the original strata from the erosion of earlier deposits in the areas from which the sediments were derived.

DEPOSITION CONTEMPORANEOUSLY WITH THE ROCK

The explanation advanced by Newberry was interpreted by the miners to indicate that the deposits would extend to great depth and that others were to be expected where the same strata were present. The decrease in value of the ores at Silver Reef with increase of depth on the dip of the ore strata and the failure to find other commercial deposits at the same horizon, have apparently led to the pretty general abandonment of Newberry's explanation for the Silver Reef deposits.

If the relation of the deposits to the Leeds anticline (see p. 154) was a factor in their formation and was not purely accidental, the theory of deposition of the ores contemporaneously with the deposition of the sediments is eliminated, for the anticline was not formed till long after the sediments. Similar relation between several of the larger copper deposits and structural features that are of much later formation than the inclosing rocks also indicates that the ores were formed later than the sediments. Certain copper deposits whose structural relations are not readily apparent may be explainable by Newberry's hypothesis, but in the absence of detailed studies to determine the less obvious structure the writer prefers to refer them to the same cause as other closely similar deposits.

Hess[2] has proposed the following explanation of the origin of the carnotite deposits of Utah and Colorado:

> It is thought possible that the sandstone deposits have been deposited in a very shallow inland sea with many islands and spits on which lodged vegetable débris which had been washed from surrounding shores. Also that sulphidic veins carrying uranium, vanadium, iron, and chromium minerals were eroded; that sulphuric acid set free by the oxidation of pyrite formed soluble sulphates of the other metals; that these were carried into the sea and on coming into contact with the vegetation were, in part at least, reduced to sulphide, though the uranium was possibly reduced to an oxide, or to some combination with vanadium. Upon the raising, draining, and oxidation of the rocks the minerals now found were formed.

This is essentially the explanation offered by Newberry for the Silver Reef deposits and may be subjected to the same tests. The close association of these deposits with the large structural features of the Plateau region suggests a genetic relation similar to that of the silver and copper deposits. These structures are much younger than the rocks, and if the association is more than accidental it eliminates the possibility of formation of the ores contemporaneously with the inclosing sediments. Some

[1] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, p. 87, 1910.

[2] Hess, F. L., A hypothesis for the origin of the carnotite deposits of Utah and Colorado: Washington Acad. Sci. Jour., vol. 4, p. 236, 1914.

extensive deposits of fossil wood at essentially the same stratigraphic horizon as the mineral deposits are barren, especially those in the sandstones southwest of the Henry Mountains (probably Salt Wash sandstone), in the Triassic in the western part of Rabbit Valley, at Circle Cliffs, and at Orange Cliffs (under the ledge).

The probability, indicated by the size of the replaced cells (see p. 153), that sulphides replaced the vegetable matter before it was carbonized may be interpreted as favoring the view that the ore deposits were formed before the wood was carbonized. A careful study of suitable material promises important results on this point. Material from these sandstones shows that the cellular structure may be preserved during carbonization quite as clearly as by replacement by silica or sulphide, though in the material examined the size of the cells indicate a shrinkage. The problem, however, is more complex than the simple determination of the time of original replacement, for it has been shown that the original sulphide can be replaced by other minerals without destroying the cellular structure.[1] It may be significant that though the replacement of wood in the shale beds of the region by iron sulphide is common, the replacement of iron sulphide by copper or other metals is not known in shale, though it is known in sandstone, where circulation is relatively free. This suggests that the original replacement may have occurred relatively early in the decomposition of the vegetable matter and that the replacement by copper may have occurred much later. The early replacement by iron is favored by the great abundance of that element in the "red beds."

CONCENTRATION BY SOLUTIONS DUE TO IGNEOUS ACTIVITY.

Evidence connecting the deposits of this type with igneous activity is not conclusive. No deposit in Utah has been positively shown to have close genetic association with igneous rocks, and several deposits are so remote from areas of such rocks as almost certainly to disprove any connection. Most of the deposits, however, are rather closely associated with laccolithic mountains or other domical uplifts that are believed to be of similar origin; and the Silver Reef deposits are in a region of igneous activity. This association naturally suggests a genetic relation with the intrusive rocks. The intrusive bodies themselves, however, so far as known, contain only small deposits of copper and none of vanadium or uranium. The existence of similar deposits in areas where igneous rocks have pretty certainly not been factors in their formation, together with the lack of a definite connection between the laccolithic bodies and the deposits, leads one seriously to doubt the existence of a direct genetic relation involving the derivation of the metallic constituents from the igneous material.

CONCENTRATION BY ATMOSPHERIC WATERS.

The idea of concentration from material disseminated in the sediments is stated by Lindgren[2] as follows:

> In considering the class as a whole it appears that igneous agencies had no part in the genesis. The ores are assuredly epigenetic and their universal appearance in land or shallow-water beds is significant. In all probability these ores have been concentrated by atmospheric waters which leached the small quantities of metals disseminated in the strata. The sediments were rapidly accumulated under arid conditions from adjacent land areas and the metals were probably carried down as fine detritus and in solutions from older ore deposits in these continental areas.
>
> The waters which concentrated the ores are believed to have been mainly sodium chloride and calcium sulphate solutions containing sulphates and perhaps chlorides of copper and lead. The mineral association and geological features indicate deposition at low temperature, probably well below 100° C., and at shallow depths but below the zone of direct oxidation. Very likely these ores have been forming continuously since the establishment of active water circulation in the beds; in favorable places below the surface concentration may now be in progress.

SOURCE OF THE METALS.

The manner in which the sediments were deposited is of importance in determining the origin of the ore bodies, but this, like the origin of the ores, is a matter concerning which there is as yet no general agreement. The sediments have been variously regarded as deposits formed in shallow seas, as continental deposits along the base of a mountainous region similar to the great plains east of the Rocky Mountains, as river and delta deposits, as wind-blown deposits, and as combinations of these. There is apparently a growing tendency to regard the sandstones, in large part at least, as of land

[1] Fath, A. E., Econ. Geology, vol. 10, pp. 140-150, 1915. Also, Rogers, A. F., Econ. Geology, vol. 11, pp. 366-380, 1916.

[2] Lindgren, Waldemar, Mineral deposits, pp. 368-369, 1913. Includes a summary of the literature.

rather than of marine or lacustrine origin, and it is generally believed that they were accumulated under arid conditions.

The derivation of the metals from the same areas as the sediments seems reasonable for the Utah deposits. Hess[1] has shown that uranium minerals are present in deposits of probable pre-Cambrian age in the Uinta Mountains, and copper deposits of the same age are present in the same region. (See p. 604.) The Triassic and Jurassic sediments were certainly not derived from the pre-Cambrian rocks of the Uinta region, for these were deeply buried beneath Paleozoic strata in Triassic and Jurassic time, but they may have come from the pre-Cambrian of areas farther to the east, where the later sedimentary formations overlap on the pre-Cambrian rocks. The presence of gold in the sediments over large areas (see p. 151) to an amount considerably in excess of that present in most sedimentary rocks further indicates derivation from a mineralized area and makes it reasonable to suppose that metals other than gold were present.

MODE OF CONCENTRATION.

Concentration of small amounts of metals disseminated through the sediments may be ascribed to circulating waters which collected the disseminated metals and redeposited them under favorable conditions. If the sediments were truly continental, circulation of waters may have been in progress when they were deposited and may have continued till they were submerged. Any circulation that took place after the elevation, folding, and faulting of the region must have been affected by the structural features. At present, at the Blue Dike prospect in White Canyon, waters that are seeping out of certain strata carry uranium, copper, and other metals, mainly as sulphates, indicating the readiness with which the metals are taken into solution. The salts are deposited as an efflorescence on the rock when the waters evaporate on reaching the surface.

Emmons[2] has attributed the movement of the solutions in the Cashin mine to an artesian circulation that found an outlet along a strong fissure in the rocks. The importance of artesian circulation in the formation of ore deposits has been emphasized by Siebenthal,[3] who has also emphasized the importance of structural relations that are apparent only on careful study. In the Silver Reef and Salt Wash deposits, for example, artesian conditions may have existed after the uplift and folding of the region. It is a well-established physiographic principle, beautifully illustrated in this region, that in the erosion of anticlines and synclines valleys develop in the anticlines, which become lines of surface drainage. It follows that if artesian conditions prevailed in a region the strata in which the waters were confined would first be tapped by the erosion of the anticlinal valleys at or near the crests of the anticlines. This would be equally true if they were tapped by the master streams (which are not controlled by the structure), for these would naturally cut the beds in the anticlines before they cut the same beds in the synclines. This might start an artesian flow along the anticline toward the outlet and from the synclines toward the anticlines, and might concentrate the flow from large areas along rather restricted zones. If, in particular areas along these zones of flowage, conditions were especially favorable to the precipitation of metallic constituents (if, for instance, there were lenses of rock rich in plant remains or in sulphide), metals in considerable amount might well be deposited. If fissures were present along the anticlines, as they are most likely to be, they would furnish an outlet to waters rising under artesian pressure. The association of some deposits with fissures is evident, as in the Cashin mine in Colorado and the Big Indian mine in Utah; and with more detailed work may be found more prevalent than is at present known.

It is believed that some such movement of the ground waters has concentrated the more soluble metallic constituents of the rocks, and has left the gold and other relatively insoluble constituents rather uniformly distributed. Such an explanation would seem to account for the association of the deposits with the folds and fissures of the region.

No satisfactory explanation of the predominance of one or more of the metals in the individual deposits and the relative paucity of others is as yet possible. So far as the ura-

[1] Hess, F. L., op. cit., p. 258.

[2] Emmons, W. H., The Cashin mine, Montrose County, Colo.: U. S. Geol. Survey Bull. 285, p. 127, 1906.

[3] Siebenthal, C. E., Origin of the zinc and lead deposits of the Joplin district: U. S. Geol. Survey Bull. 606, 1915.

nium-vanadium deposits are concerned, Hess[1] has suggested that the original area of uranium and vanadium bearing rocks was small and that sediments from it were not widely scattered. A similar explanation may of course apply to the silver deposits. However, as the areas from which the sediments were derived and the character of their mineralization are both uncertain, any explanation must be tentative.

Alteration by surface solutions has been important. It is discussed on page 207.

The commercial deposits of manganese are believed by Harder and Pardee to have resulted from the concentration from earlier deposits during the erosion of the region.

AGE OF THE DEPOSITS.

The age of the deposits depends upon their mode of origin. If they were deposited with the sediments they are of course of the same age as the inclosing rocks. If they are due to the igneous activity of the region they are doubtless of Tertiary age. If, as the writer believes to be true, they were formed after the uplifting, folding, and faulting of the region their formation began in Tertiary time and in places may be still in progress.

SUMMARY.

All the deposits in the sandstones of the Plateau province, whether mined for silver, for copper, or for uranium and vanadium, are believed to be of one type. Deposits in which certain metals or groups of metals predominate range widely both geographically and geologically. Copper has the widest distribution; uranium and vanadium and silver are more restricted in area and in the age of the rocks in which they occur. The genetic relation between the structural features of the region and the ore deposits is believed to be intimate. The deposits are regarded as having been formed by circulating waters that collected the metals disseminated through the sedimentary rocks and deposited them on contact with carbonaceous matter, earlier sulphides, or other precipitating agents. The circulation in some places is believed to have been of artesian character and to have been controlled to a large extent by structural features. Most of the minerals at present exposed are the products of alteration of the original minerals by surface solutions. The formation of the deposits probably began in Tertiary time, and in places is possibly still in progress.

[1] U. S. Geol. Survey Bull. 625, p. 334, 1917.

DEPOSITS DUE TO CONCENTRATION EFFECTED BY THE INTRODUCTION (POSSIBLY INDEPENDENTLY OF IGNEOUS ACTIVITY) OF SUBSTANCES FOREIGN TO THE ROCK.

Certain replacement deposits that have formed along fissures or faults in sedimentary rocks, mainly limestones, are not closely associated with igneous rocks, and the origin of their metallic constituents is not known. They may or may not have been introduced from igneous sources.

In this class are the hematite deposits of the Uinta Mountains, the copper deposits of the Dyer mine north of Vernal in the same range, and the copper and lead deposits in the Beaver Dam Mountains in the southeastern part of the State. In the northern and southern parts of the Wasatch Range and in the North Tintic district are lead-zinc deposits low in silver and copper that are remote from important igneous intrusions but that are similar in general character to deposits whose derivation from igneous sources can be directly traced.

In the Uinta Range there are no exposures of igneous rocks that are younger than the sediments in which the deposits occur, except in the pre-Cambrian rocks, though (see p. 252) the structure of the range may be interpreted as the result of an extensive intrusion.

Sources of the metals other than igneous are easily possible. Iron may have been derived from the quartzite and shale, in which it is abundantly present; and a similar origin for the copper and for the other deposits is entirely possible. At least some of these deposits may have been derived from material leached from underlying strata and deposited at places where the solutions rose along fissures in the limestones, but their similarity in composition and in structural relations to deposits directly associated with igneous intrusions leaves the matter in doubt. The geology of this type of deposit has nowhere in the State been studied in detail and for the present its genesis must be regarded as undetermined.

DEPOSITS DUE TO CONCENTRATION OF SUBSTANCES INTRODUCED BY IGNEOUS ACTIVITY.

DISTRIBUTION.

By far the greater number of deposits within the State are so closely associated with intrusive rocks that there can be no reasonable doubt that their formation was directly due to igneous activity. Ore deposits are most numerous and most extensive in the zones of greatest igneous activity (see p. 91) and are associated with igneous rocks in other localities, as in the Raft River and Pilot ranges and in the southeastern part of the State.

CLASSIFICATION.

Ore deposits associated with the igneous rocks may be conveniently separated into three groups—those in intrusive rocks, those in extrusive rocks, and those in sedimentary rocks. A few individual deposits occur partly in one type of rock and partly in another, but most deposits occur in one type only. Each group may be further subdivided according to mineralogic associations, geologic relations, or metal content.

DEPOSITS IN INTRUSIVE ROCKS.

The deposits in the intrusive rocks differ greatly in mineral association and in the metals for which they are chiefly valuable, but for the most part they agree in containing minerals formed only at relatively high temperature and pressure. Gradation between the different types indicates that all represent stages in a single process rather than deposits formed during separate periods.

VEINS CLOSELY ALLIED TO PEGMATITE.

PEGMATITIC GOLD QUARTZ VEINS.

Pegmatitic gold quartz veins are present in the Park Valley district of the Raft River Range and in the Spring Creek district of the Deep Creek Range. In both districts the veins extend from the intrusive into the adjacent sedimentary rocks. In the Queen of Sheba mine in the Deep Creek Range most of the ore has been taken from the portions inclosed in the quartzite, and in the Park Valley district practically all of it has been taken from the portions in the granite. The typical gangue mineral of the ore shoots is a rather fine grained vuggy quartz containing sulphides and arsenides, commonly in small amounts, in the primary ore and the oxidation products of these in the oxidized portion of the veins. This finer vuggy quartz of the ore shoot gives place along the dip or strike (as in the Queen of Sheba vein) or from the middle toward the wall (as in parts of the Century vein) to coarser pegmatitic quartz which in turn grades into a mixture of quartz and feldspar. With the increase of the coarse pegmatitic quartz or the feldspar the metallic minerals greatly decrease, and the vein filling ceases to be ore.

The gradation from pegmatitic material to metal-bearing vein quartz indicates that the ore shoots have resulted from a differentiation of the magmatic material that filled the fissures. Opportunity for a study of this type of deposit has been rather slight, but the segregation of the feldspathic constituents along the walls, as in the Century vein, suggests that the vein was first filled with siliceous magmatic material derived from the earlier crystallization of the main granitic rock and that the earliest minerals to crystallize were collected along the walls, and that the latest, including the quartz and sulphides, were segregated toward the center. In the Queen of Sheba vein there are some indications that the feldspathic material decreased and the metallic constituents increased with increasing distance from the granitic rock, but developments within the granitic rock at the time of study were altogether too slight to permit of a definite conclusion on this point. Both the Century and Queen of Sheba deposits are associated with intrusive bodies in Cambrian or pre-Cambrian rocks, indicating deep-seated conditions, with high temperature and pressure. No similar deposits have been found far from the intrusive rocks. This suggests that the contacts of these deep-seated intrusives with the sedimentary rocks were favorable to the formation of this type of deposit. The production from such deposits in Utah has been relatively small.

Spurr[1] has described similar but more productive deposits from the Silver Peak district, Nev., where more extensive developments afford better opportunity for study. Spurr considers that the Nevada deposits have resulted from a differentiation of alaskite (pegmatite), which, in turn, he believes was a differentiation product of a granitic magma.

[1] Spurr, J. E., Ore deposits of the Silver Peak quadrangle, Nev.: U. S. Geol. Survey Paper 55, 1906.

QUARTZ-TOURMALINE-SCHEELITE VEINS.

Quartz-tourmaline-scheelite veins are known only from the Clifton district near the northern end of the Deep Creek Range and have been but slightly developed there. The deposits are in quartz monzonite, probably a part of the same intrusion as the larger Ibapah stock in the southern part of the range, with which the pegmatitic gold veins of the Queen of Sheba mine are associated. (See p. 485.) So far as determined, the primary minerals are coarsely crystalline quartz, orthoclase, amphibole, tourmaline, a little epidote and iron bearing carbonate, a little apatite, and the metallic minerals magnetite, molybdenite, and scheelite. At the surface the minerals have been partly oxidized, especially the molybdenite, which has been largely altered to powellite; and a little copper carbonate is present, which has doubtless resulted from oxidation of copper-bearing sulphides. Gold is also said to be present in small amount. The minerals, notably the scheelite, appear to be segregated in the vein; some lenses consist largely of scheelite, but in much of the vein this mineral is in small amount or is lacking.

Alteration of the quartz monzonite has extended but a short distance from the veins. The resultant rock is composed essentially of quartz, muscovite (sericite), chlorite, and some iron oxide. The chlorite may have resulted from the surface alteration of an earlier magnesian mineral, though no remnant of such was detected.

A pegmatite dike associated with the veins consists of coarsely crystalline pink feldspar, quartz, and amphibole, with no metallic constituents. The feldspar and amphibole are similar to those in the metal-bearing veins, and this, together with the close association, suggests that both dike and veins were differentiation products of the same magmatic material, which itself was probably a differentiate from the magma that formed the main mass of the quartz monzonite.

So far as known, the only output from this type of deposit has been a few tons of scheelite ore.

Scheelite-bearing pegmatites are known in Maine and Idaho, and pegmatites containing other tungsten minerals are relatively common. No important production of tungsten from scheelite-bearing pegmatites is known.

QUARTZ-TOURMALINE COPPER VEINS.

Quartz-tourmaline copper veins are present in the Clifton district (p. 517) in the Deep Creek Range and in the San Francisco district of the San Francisco Range (p. 517). In both districts the veins are in quartz monzonite of similar character. The differences in both the gangue minerals and the metallic minerals in the two districts are rather marked, but the similarities are far more striking.

In the Clifton district the usual gangue minerals are quartz, tourmaline, carbonate (probably iron-magnesium-manganese carbonate), amphibole, diopside, vesuvianite, garnet, and in some veins epidote; apatite and titanite occur in most veins, danburite in several, and fluorite and orthoclase in a few. The metallic minerals pyrite, chalcopyrite, magnetite, and hematite are universally present, and in some veins the iron oxides are abundant. Scheelite was noted in several veins and possibly is present in most of them in small amount. The veins contain some gold and silver. Galena is present in some veins but is probably abundant in none.

The Cactus vein in the San Francisco district is composed of quartz, tourmaline, magnesium-manganese-iron carbonate, and lesser amounts of anhydrite and barite as the principal gangue minerals, and of pyrite, chalcopyrite, and hematite as the important metallic minerals. The vein contains also small amounts of tetrahedrite and galena.

The deposits are similar in containing abundant quartz, tourmaline, carbonate, and oxides of iron. Those of each district contain several minerals not present in the other, but the chemical differences are not so marked, for though the Cactus deposit contains no magnesium silicates it contains notable amounts of magnesium-bearing carbonate, and though the Clifton deposits are not known to contain anhydrite they contain calcium in the form of carbonate.

The quartz monzonite adjacent to the veins alters characteristically to a rock composed essentially of quartz and mica, muscovite (sericite) being associated with the Cactus vein and biotite as well as muscovite with the Clifton veins. A green mica and chlorite are present among the alteration products in the Clifton district but have probably resulted from the alteration of the biotite. The alteration of the wall rock of these veins is compared with that of other types on page 164.

ORIGIN AND OUTPUT OF THE DEPOSITS.

The similarity seen in the Clifton district between the quartz-tourmaline copper veins and the quartz-tourmaline-scheelite deposits leaves no doubt that they had a common origin, both being probably differentiates from igneous material which in part crystallized as barren pegmatite, in part as metalliferous pegmatite, and in part as true veins.

The output from this type of deposit has not been large and is practically all derived from the Cactus mine, though there has been considerable development on veins of this type in the Clifton district.

SIMILAR DEPOSITS IN OTHER REGIONS.

Quartz-tourmaline copper deposits occur[1] in many localities outside of Utah, particularly at Meadow Lake, Nevada County, Cal.,[2] where the veins are in granitic and dioritic rocks, and in the Blue Mountains, Oreg.,[3] where they are in diabase and diorite. Tourmaline veins are numerous in the Helena region, Mont.,[4] where Knopf has distinguished tourmaline silver-lead, tourmaline silver-copper, and tourmaline gold veins.

QUARTZ COPPER VEINS.

Quartz copper veins have been developed on a commercial scale in two districts, and closely allied deposits are present in other districts. They show by far their greatest extent and importance in the Bingham district where their yield of copper has been very large for several years and probably will continue to be so for many years to come, but they have yielded considerable metal in the Beaver Lake district and are possibly present in other districts. Closely allied gold-copper deposits have been developed to a slight extent in the La Sal and Henry mountains. The quartz copper veins are characterized by the dominance of quartz as gangue (though a little orthoclase is sometimes present) and by the occurrence of the metals chiefly in sulphides. They are typically replacement veins, filling fissures and replacing the adjacent rock, which is quartz monzonite or quartz monzonite porphyry. The deposits are in places confined to a definite vein or to a few veins, and in places consist of a stockwork of small veins permeating a large body of minutely fissured rock. The former type occur in the Beaver Lake district, and the stockwork is represented by the great disseminated deposits of the Bingham district. In both the characteristic gangue is quartz and the original metallic minerals are mainly pyrite and chalcopyrite but include small amounts of molybdenite.

The alteration of the quartz monzonite adjacent to the fissures shows considerable variation. In the O. K. mine in the Beaver Lake district, what appears to have been the main mineralizing channel, is a roughly cylindrical "pipe" of coarse pegmatitic quartz, from which small branching veins of quartz and of quartz and sulphide extend into the surrounding rock. (See fig. 54.) The quartz monzonite adjacent to the veins has been altered to a rock consisting essentially of quartz and muscovite (sericite), accessory minerals, and sulphides of iron and copper.

In the Bingham district the earlier stages of alteration resulted in the transformation of the hornblende and augite into biotite, in the partial sericitization of the feldspars, and in the transformation of much of the groundmass of the rock into a fine-grained aggregate of quartz and orthoclase known as "dark porphyry." Pyrite and chalcopyrite are scattered through the rock. Where the alteration has been more intense the rock has been largely converted into a fine-grained aggregate of quartz and orthoclase, some sericite, and small disseminated grains of pyrite and chalcopyrite. This is known as "light porphyry." The chemical and mineralogic changes in the wall rock are compared with those of other localities on pages 153–157.

The deposits in the La Sal and Henry mountains are, in general, similar in character to those of the Beaver Lake district, though most of the veins are small and the action of the mineralizing solutions on the rocks adjacent to the fissures has been feeble. The precious-metal content of the veins in the La Sal and Henry Mountains is higher than in the other districts.

Much of the ore of these deposits has resulted from the alteration and concentration of original metallic minerals by surface solutions. (See p. 208.) The general similarity of these

[1] Lindgren, Waldemar, Metasomatic processes in fissure veins: Am. Inst. Min. Eng. Trans., vol. 30, pp. 626–643, 1901.

[2] Lindgren, Waldemar, The auriferous veins of Meadow Lake, Calif.: Am. Jour. Sci., 3d ser., vol. 46, p. 201, 1893.

[3] Lindgren, Waldemar, The gold belt of the Blue Mountains of Oregon: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 2, p. 629, 1901.

[4] Knopf, Adolph, Ore deposits of the Helena mining region, Mont.: U. S. Geol. Survey Bull. 527, 1913.

deposits to the quartz-tourmaline copper veins leaves no doubt of their close relation and indicates that both were deposited from solutions that had resulted from the differentiation of the quartz monzonite magma.

The main production from deposits of this type has been in copper from the Bingham districts. In recent years it has been large and will continue so for many years to come.

In other western States deposits of this type are numerous and many of them are large and of great commercial importance. Those at Ely, Nev.,[1] correspond most nearly to those at Bingham. Similar deposits occur at Santa Rita,[2] N. Mex., at Morenci,[3] Globe,[4] Ray,[5] Bisbee,[6] and in the Ajo district,[7] Ariz., and in many other less developed districts. The deposits at Butte,[8] Mont., show many similarities to this type.

QUARTZ SILVER-LEAD VEINS.

The gangue of the quartz silver-lead veins, though chiefly quartz, locally contains a good deal of barite. Pyrite and galena are the most abundant metallic minerals, though sphalerite is commonly present, and copper as chalcopyrite or as the antimony or arsenic minerals, tetrahedrite or enargite, is locally present in small amounts. Silver in some combination is present in the galena and probably in the other metallic minerals. The deposits commonly occupy a rather definite fissure or a series of fissures forming a lode.

The wall rock has been conspicuously altered for only a short distance from the fissures. In the Bingham district, in the Last Chance mine, it has been changed, immediately adjacent to the fissures, to a rock composed essentially of quartz, muscovite (sericite), and secondary orthoclase. In the Tintic district sericitization appears to have been the common alteration. The change in the wall rock is similar to that in the quartz copper veins but has apparently been less extensive. The mineralogic changes in the two are compared on pages 163–167.

The most important deposits occur in the Bingham and Tintic districts. Small veins are known in the San Francisco and other districts but so far have not been commercially important.

A type of deposit differing somewhat from the quartz silver-lead veins is present in the Clifton district. The veins are composed essentially of quartz and calcite (probably containing iron), whose relative amounts differ in different veins and in different parts of a single vein. The important original metallic mineral is "argentiferous" galena. The characteristic alteration of the wall rock is pronounced sericitization. These deposits differ from those of the Bingham and Tintic districts, chiefly by containing abundant carbonates. The quartz silver-lead veins from the Bingham and Tintic districts have yielded important amounts of metal, though much less than other types of silver-lead deposits.

GOLD QUARTZ VEINS.

Some veins in the Clifton district appear to be chiefly valuable for their gold. The wall rock is quartz monzonite, and the principal gangue mineral is quartz with some carbonates. In many places specular hematite is abundantly scattered through the quartz in fine flakes, giving it a dark appearance. Pyrite and chalcopyrite are commonly present in small amount, and galena and sphalerite have been noted. The gold is said to occur free. The wall rock has undergone sericitization of the feldspar and chloritization of the magnesian minerals.

The output from this type of vein has been small, being thus far confined to the yield of a few rich "pockets."

MAGNETITE-HEMATITE VEINS.

In the Iron Springs district some veins in the intrusive bodies of quartz monzonite porphyry consist essentially of magnetite and hematite with a little quartz gangue and oxidized copper and lead minerals in small amount. The most notable change in the wall rock has apparently been the addition of soda, probably in the form of albite.

A small vein very similar to those in the Iron Springs district is inclosed in quartz monzonite porphyry in the Henry Mountains on the

[1] Spencer, A. C., The geology and ore deposits of Ely, Nev.: U. S. Geol. Survey Prof. Paper 96, 1917.

[2] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, p. 306, 1910.

[3] Lindgren, Waldemar, The copper deposits of Clifton-Morenci district. Ariz.: U. S. Geol. Survey Prof. Paper 43, 1905.

[4] Ransome, F. L., The Globe and Miami districts: U. S. Geol. Survey Bull. 529, pp. 183-186, 1913.

[5] Ransome, F. L., Ray, Ariz.: U. S. Geol. Survey Bull. 529, p. 186, 1913.

[6] Jenney, J. B., Bisbee porphyry deposits: Eng. and Min. Jour., vol. 97, p. 467, 1914.

[7] Joralemon, I. B., The Ajo copper mining district: Am. Inst. Min. Eng. Bull. 92, pp. 2011–2328, 1914.

[8] Weed, W. H., Geology and ore deposits of the Butte district, Mont., U. S. Geol. Survey Prof. Paper 74, 1912. Sales, R. H., Am. Inst. Min. Eng. Trans., vol. 46, pp. 3-106, 1914.

Cuprum claim. The principal vein mineral is magnetite with a little quartz gangue and commonly some copper carbonates, probably derived from the oxidation of sulphides.

Deposits of this character have made no production, though those of the Iron Springs district contain important amounts of iron ore.

In the Antelope Range, northeast of Marysvale, Piute County, deposits of hydrous oxides of iron and manganese are associated with rather indistinct fissures. The inclosing rock is quartz monzonite porphyry which has been intensely altered, essentially to cherty quartz containing small specks of iron oxide. The iron minerals are yellow and red hydrous oxides in vuggy porous masses, many of which show beautiful stalactitic structure. The minerals, as they now exist, appear to have resulted from the alteration of some earlier mineral or minerals and in many respects resemble the gossan resulting from the oxidation of a sulphide body. No remnants of sulphide were, however, observed in the ore at the shallow depth to which developments have been carried. Iron has been removed from a large body of the adjacent altered quartz monzonite, and may have been redeposited in the fissures, but no very definite statement as to the origin of the deposit is warranted.

The deposit in the Tintic or Dragon iron mine in the Tintic district is somewhat similar to the deposits of the Antelope Range, though it is on the contact of quartz monzonite and limestone. Both the quartz monzonite and the adjacent volcanic rocks at the Tintic mine have been sericitized and pyritized. They formerly covered the present surface to a depth of 1,000 feet or more, and the iron-ore deposit is attributed (p. 415) to downward concentration of the iron from the now eroded and superficial portions and to replacement of limestone by it along the contact.

The Tintic iron deposits have yielded a considerable tonnage of ore, which has been mainly used for flux, and those of the Antelope Range have furnished some shipments. Both deposits are said to contain small amounts of precious metals.

RELATIONS OF DIFFERENT VEIN TYPES IN THE IGNEOUS ROCKS.

Most of the types of veins in igneous rocks are closely related, and some types grade into others. Such transitions in one district give good ground for the interpretation of deposits in districts where the full series is not represented. Broadly speaking, all the types seem to be due to deposition by rather similar solutions, and their differences appear to be largely due to the physical conditions under which the deposition took place.

MINERALIZING SOLUTIONS.

The character of the mineralizing solutions may be deduced from the mineral composition of the veins and from a comparison of the altered with the unaltered wall rock.

Mineral composition of the veins.—The following table shows the important mineral constituents in the different veins:

Principal vein minerals present in different types of deposits in intrusive rocks.

Minerals.	Quartz-tourmaline-scheelite veins.	Quartz-tourmaline copper veins.	Quartz copper veins.	Quartz silver-lead veins.	Gold quartz veins.	Iron veins.	Pegmatitic gold quartz veins.
Quartz	×	×	×	×	×	×	×
Orthoclase	×	×					×
Amphibole	×	×					
Tourmaline	×	×					
Barite		×	×				
Carbonate	×	×					
Magnetite	×	×				×	
Hematite		×	×		×	×	
Scheelite	×	×					
Molybdenite	×		×				
Apatite		×					
Danburite		×					
Pyrite		×	×	×	×		×
Chalcopyrite		×	×	×	×		
Anhydrite		×					
Galena				×			
Sphalerite				×			
Tetrahedrite				×			
Arsenopyrite							×
Gold					×		×

Alterations in the wall rock.—The alteration of the wall rock adjacent to the veins is an important indication of the nature of the solutions

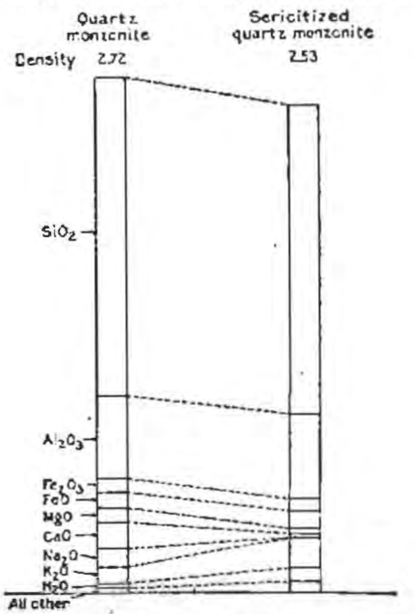


FIGURE 25.—Diagram showing gain or loss in grams of each constituent in alteration of 100 cubic centimeters of quartz monzonite wall rock of tourmaline-quartz copper vein at Cactus mine, San Francisco district, Beaver County. Scale, 1 inch=50 grams.

that carried constituents of the ores and of the conditions under which the ores were deposited.

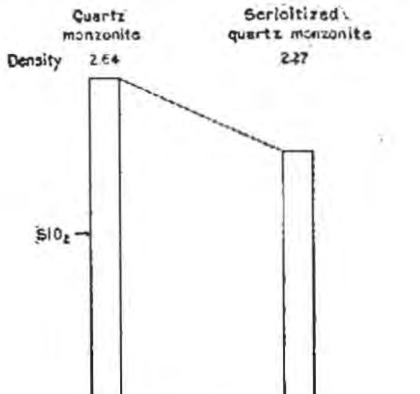


FIGURE 26.—Diagram showing gain or loss in grams of each constituent in sericitization of 100 cubic centimeters of quartz monzonite wall rock of quartz copper veins at O. K. mine, Beaver Lake district, Beaver County. Scale, 1 inch=50 grams.

Practically everywhere the character of the alteration depends on the intensity of the action. Thus, adjacent to a strongly mineralized fissure the rock is changed to an aggregate of quartz and mica (sericite), which at a greater distance grades into rock composed of quartz, mica, chlorite, epidote, calcite, and the like; and the latter group of minerals characterize the alteration adjacent to a feebly mineralized fissure.

The veins in the intrusive rocks of the Tintic district are lead-copper veins with quartz and barite as the principal gangue minerals. The alteration adjacent to the veins has been characteristically to a quartz-sericite rock carrying pyrite, though close to the veins it may be composed largely of quartz

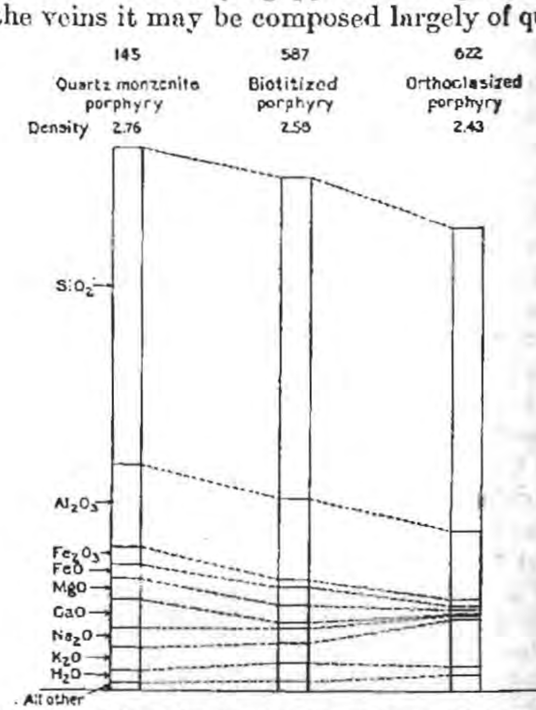


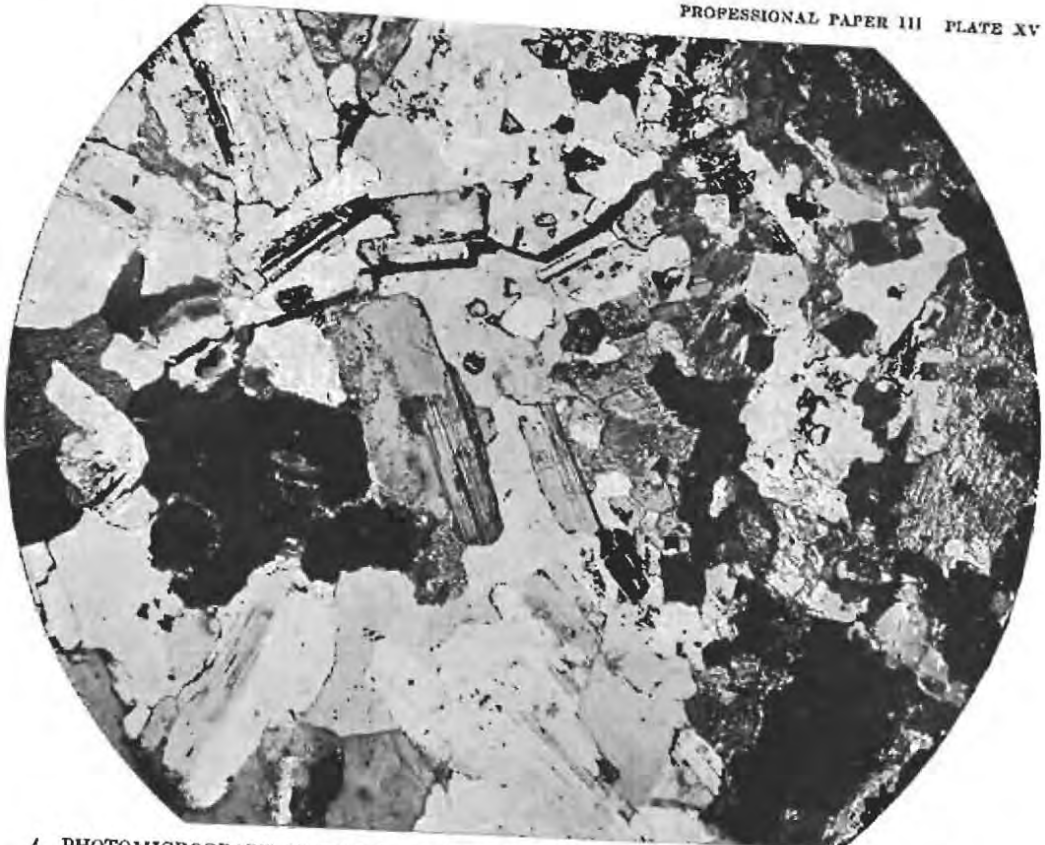
FIGURE 27.—Diagram showing gain or loss in grams of each constituent in alteration of 100 cubic centimeters of quartz monzonite wall rock of quartz copper veins of Bingham district by addition of biotite and orthoclase. Scale, 1 inch=50 grams.

and barite and at a distance may carry important chlorite, epidote, and calcite.

Plate XV illustrates the change to quartz-sericite rock adjacent to the quartz-tourmaline copper deposit of the Cactus mine; and Plate XVI illustrates the change of quartz monzonite porphyry of the Bingham district to a rock composed of quartz, biotite, orthoclase, and sericite and finally to a rock composed largely of quartz and secondary orthoclase, with some biotite and sericite.

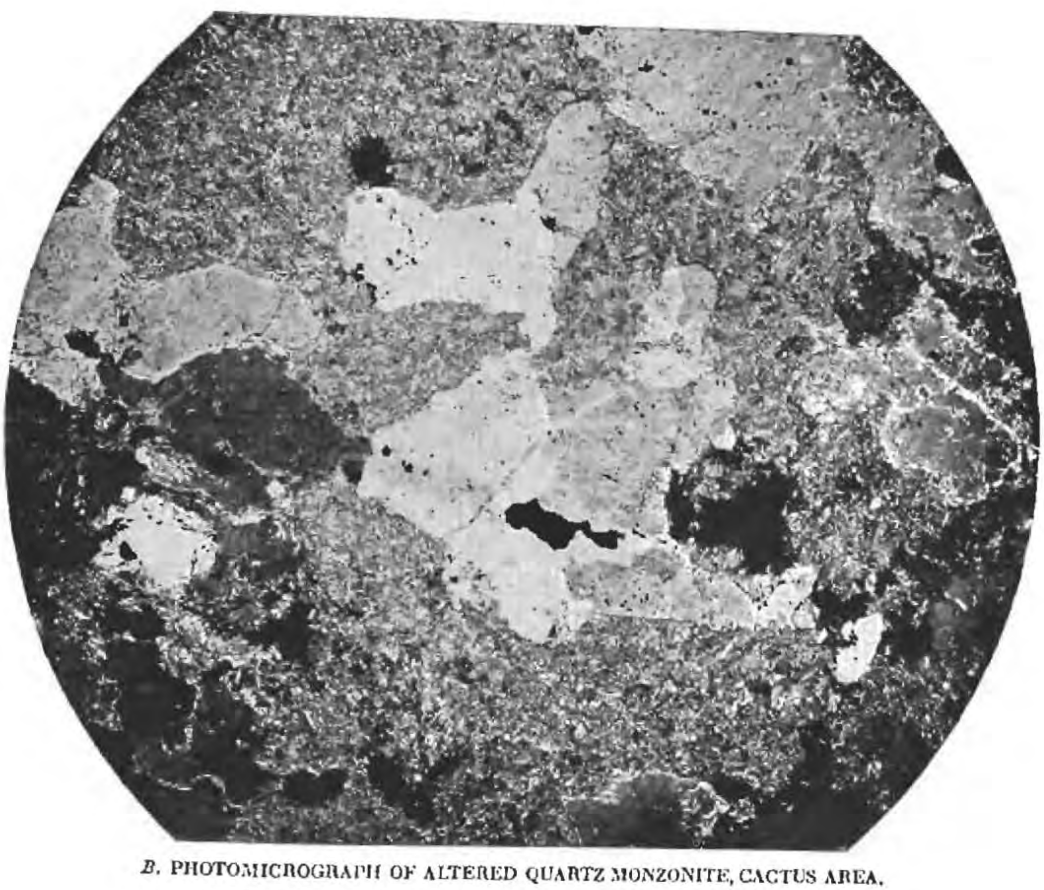
Figures 25–27 indicate graphically the chemical changes in certain of these types. This form of diagram has been employed by J. B. Umpleby [1] in showing the changes in rock composition in hydrothermal alteration.

[1] The genesis of the Mackay copper deposits, Idaho: Econ. Geology, vol. 10, pp. 307-358, 1915.



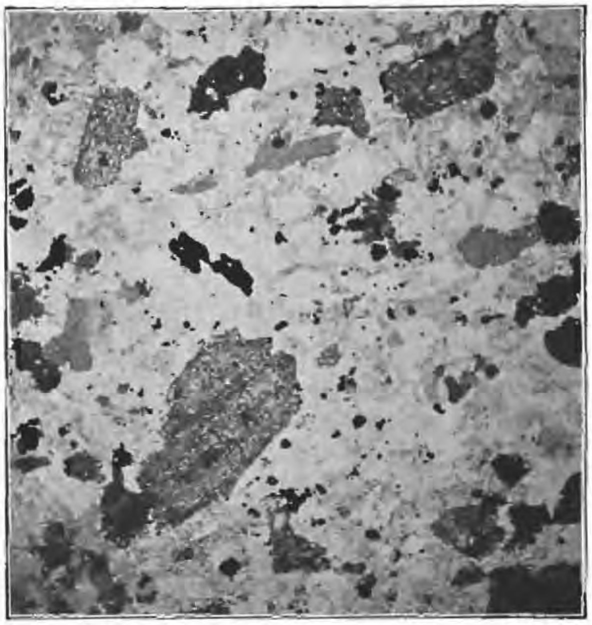
A. PHOTOMICROGRAPH OF QUARTZ MONZONITE OF CACTUS AREA, SAN FRANCISCO DISTRICT.

Crossed nicols. Enlarged 30 diameters.



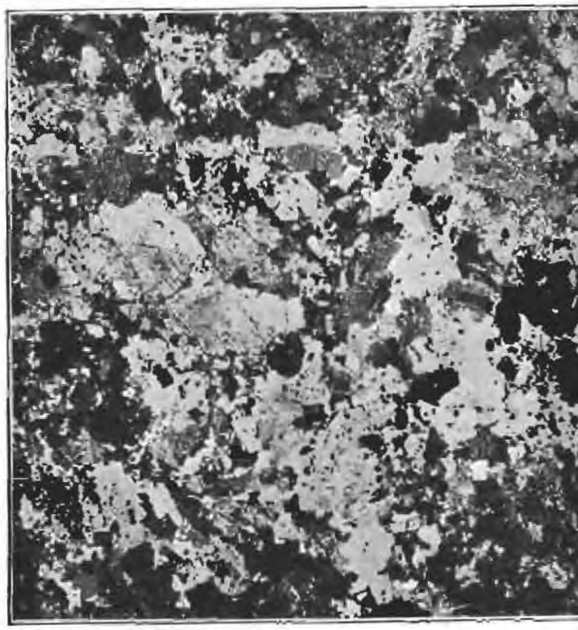
B. PHOTOMICROGRAPH OF ALTERED QUARTZ MONZONITE, CACTUS AREA.

Felted area, sericite; clear areas, quartz. Enlarged 30 diameters.



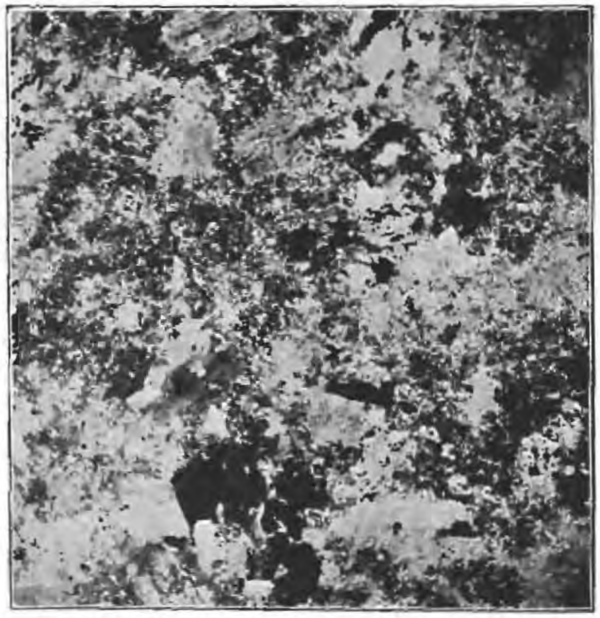
A. PHOTOMICROGRAPH OF QUARTZ MONZONITE PORPHYRY, BINGHAM DISTRICT.

Ordinary light. Enlarged 30 diameters.



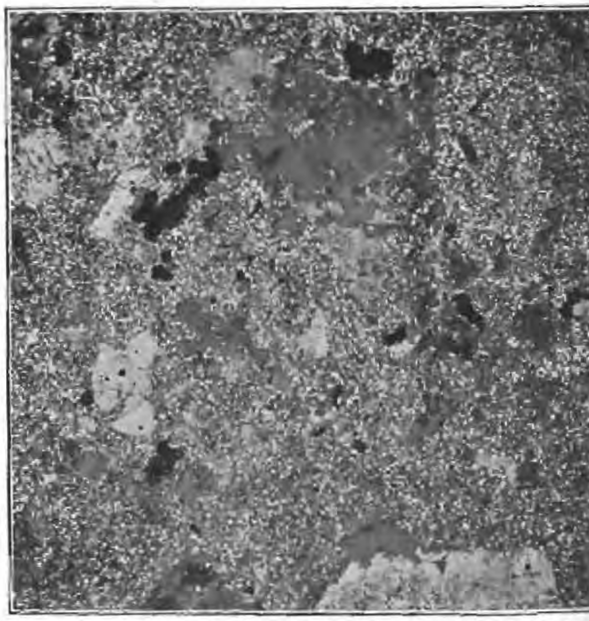
B. PHOTOMICROGRAPH OF QUARTZ MONZONITE PORPHYRY, BINGHAM DISTRICT.

Crossed nicols. Enlarged 30 diameters.



C. PHOTOMICROGRAPH OF QUARTZ MONZONITE PORPHYRY ENRICHED WITH BIOTITE, BINGHAM DISTRICT.

Small dark areas, secondary biotite; light areas, muscovite, quartz, and orthoclase. Enlarged 30 diameters.



D. PHOTOMICROGRAPH OF QUARTZ MONZONITE PORPHYRY ENRICHED WITH ORTHOCLASE, BINGHAM DISTRICT.

Small, light areas, orthoclase. Enlarged 30 diameters.

The following tables show the chemical and mineralogic changes that have taken place in the alteration of the wall rocks of the different types of veins:

Alteration of wall rock of tourmaline-quartz veins.

Analyses.

	1	1a
SiO_2	62.10	62.56
Al_2O_3	15.47	17.21
Fe_2O_3	2.64	2.29
FeO	3.15	3.64
MgO	2.57	1.13
CaO	5.31	.29
Na_2O	3.56	.07
K_2O	3.15	6.02
H_2O-	.14	.14
H_2O+	.72	2.70
TiO_2	.81	.70
CO_2	Trace.	1.93
P_2O_5	.27	.24
SO_3	....	.02
S	....	.13
MnO	....	.45
Cu	....	.09
	99.89	99.61
Density	2.72	2.53

Weight of the principal oxides (grams in 1 cubic centimeter).

	1	1a	Increase (+) or decrease (−).
SiO_2	1.689	1.582	−0.107
Al_2O_3	.420	.435	+ .015
Fe_2O_3	.071	.057	− .014
FeO	.085	.092	+ .007
MgO	.069	.028	− .041
CaO	.144	.007	− .137
Na_2O	.096	.001	− .095
K_2O	.085	.152	+ .067
H_2O-	.003	.003	.000
H_2O+	.019	.068	+ .049
TiO_2	.022	.017	− .005
CO_2	.000	.048	+ .048

Mineral composition calculated from chemical analyses.

	1	1a	Increase (+) or decrease (−).
Quartz	16.20	38.16	+21.96
Orthoclase molecule	16.68	6.12	−10.56
Albite molecule	28.82	....	−28.82
Anorthite molecule	15.57	....	−15.57
Hornblende	13.48	....	−13.48
Biotite	5.24	....	− 5.24
Magnetite	2.09	3.25	+ 1.16
Titanite	1.57	.20	− 1.37
Apatite	.67	.34	− .33
Muscovite (sericite)	....	42.98	+42.98
Pyrite	....	.12	+12
Rutile	....	.64	+64
Iron carbonate	....	3.95 } 4.98	+3.95 } 4.98
Magnesium carbonate	....	.34	+ .34
Manganese carbonate	....	.69	+ .69
Serpentine	....	2.23	+ 2.23

1. Fresh quartz monzonite, Copper Gulch, Beaver County; George Steiger, analyst.
1a. Altered quartz monzonite, Copper Gulch, Beaver County; R. C. Wells, analyst.

Alteration of wall rock of quartz copper veins (sericitization of wall rock).

Analyses.[a]

	2	2a
SiO_2	64.41	66.87
Al_2O_3	15.85	18.14
Fe_2O_3	1.92	1.36
FeO	2.52	1.06
MgO	1.66	.68
CaO	3.71	.11
Na_2O	3.60	.61
K_2O	3.46	4.12
H_2O-	.12	.87
H_2O+	1.09	4.05
TiO_2	.43	.85
CO_2	.72	None.
P_2O_5	.23	.05
SO_3	None.	.05
S	None.	.23
MnO	.07	None.
Cu	....	.70
	99.79	99.75
Density	2.64	2.27

[a] R. C. Wells, analyst.

Weight of the principal oxides (grams in 1 cubic centimeter).

	2	2a	Increase (+) or decrease (−).
SiO_2	1.700	1.518	+0.182
Al_2O_3	.418	.411	− .007
Fe_2O_3	.050	.030	− .020
FeO	.066	.024	− .042
MgO	.043	.015	− .028
CaO	.097	.002	− .095
Na_2O	.095	.013	− .082
K_2O	.091	.093	+ .002
H_2O-	.003	.019	+ .016
H_2O+	.028	.092	+ .064
TiO_2	.011	.000	− .011
CO_2	.019	.001	− .018

Mineral composition calculated from chemical analyses.

	2	2a	Increase (+) or decrease (−).
Quartz	23.16	42.90	+19.74
Orthoclase molecule	16.12	....	−16.12
Albite molecule	29.87	5.24	24.63
Anorthite molecule	10.56	....	−10.56
Hornblende	4.70	....	− 4.70
Biotite	7.76	....	− 7.76
Magnetite	2.87	....	− 2.87
Titanite	.59	....	− .59
Apatite	.34	.34	....
Calcite	1.60	....	− 1.60
Muscovite (sericite)	1.59	35.02	+33.43
Chalcopyrite	....	.79	+ .79
Rutile	....	.85	+ .85
Chlorite	....	[a]3.78	+ 3.78
Kaolinite	....	7.48	+ 7.48
Limonite	....	2.99	+ 2.99

[a] Clinochlore, MgO:FeO::17:14.

2. Fresh quartz monzonite, vertical shaft, O. K. mine, Beaver County.
2a. Altered quartz monzonite, stope shaft, O. K. mine, Beaver County.

Alteration of monzonite wall rock adjacent to fissure, Bingham district.

Analyses.

	1	2	3	4
SiO_2	58.64	63.09	66.27	56.78
Al_2O_3	15.35	16.33	15.01	16.90
Fe_2O_3	3.25	1.37	1.84	6.87
FeO	2.54	3.29	.39	2.34
MgO	3.84	3.53	.71	.03
CaO	5.37	.70	.18	1.18
Na_2O	3.60	2.79	.72	.37
K_2O	4.23	3.91	9.62	7.02
H_2O-	.86	.95	.34	1.32
H_2O+	1.50	2.35	1.50	2.23
TiO_2	.83	.43	.47	.81
CO_2	None.	None.	None.	.26
P_2O_5	.02	.42	.16	.04
S	.05	.67	1.66	5.93
Cr_2O_3	Trace.	....	....	Trace.
MnO	Trace.	None.	None.	Trace.
BaO	.18	.09	.17	.14
ZrO_2	....	None.	None.	....
SO_3	....	None.	None.	....
Cl	....	None.	None.	....
F	....	.08	.15	....
SrO	....	Trace.	Trace.	....
CuO	....	.55	1.62	....
	100.26	100.55	100.81	102.22
O equivalent to S	.02	.37	.90	2.22
	100.24	100.18	99.91	100.00
Density	2.76	2.58	2.43	....

Weight (grams in 1 cubic centimeter of rock).

	1	2	3	Increase (+) or decrease (−).	
				2	3
SiO_2	1.618	1.627	1.551	+0.009	−0.067
Al_2O_3	.424	.421	.351	− .003	− .073
Fe_2O_3	.090	.035	.043	− .055	− .047
FeO	.070	.085	.009	+ .015	− .061
MgO	.106	.091	.017	− .015	− .089
CaO	.148	.018	.004	− .130	− .144
Na_2O	.099	.072	.017	− .027	− .082
K_2O	.117	.101	.225	− .016	+ .108
H_2O-	.024	.024	.008	.000	− .016
H_2O+	.041	.061	.035	+ .020	− .006
TiO_2	.023	.011	.011	− .012	− .012
ZrO_2	....	....	....	....	....
CO_2	....	....	....	....	....
P_2O_5	.001	.011	.004	+.010	+.003
SO_3	....	....	....	....	....
Cl	....	....	....	....	....
F	....	.002	.004	+.002	+.004
S	.001	.017	.039	+.016	+.038
Cr_2O_3	....	....	....	....	....
MnO	....	....	....	....	....
BaO	.005	.002	.004	−.003	−.001
SrO	....	....	....	....	....
CuO	....	.014	.038	+.014	+.038

Mineral composition calculated from chemical analyses.

	1	2	3	4	Increase (+) or decrease (−).		
					2	3	4
Quartz	13.20	30.54	25.26	26.28	+17.34	+12.06	+13.08
Orthoclase molecule	23.35	9.45	47.82	21.13	−13.90	+24.47	− 2.22
Albite molecule	30.39	9.96	4.19	3.14	−20.43	−23.20	−27.25
Anorthite molecule	8.06	2.78	.83	3.89	− 5.28	− 7.23	− 4.17
Augite	12.70	....	....	....	−12.70	−12.70	−12.70
Biotite	5.50	29.19	5.05	....	+23.69	− .45	− 5.50
Magnetite	4.41	....	....	2.00	− 4.41	− 4.41	− 2.41
Sphene	.78	....	....	....	− .78	− .78	− .78
Muscovite molecule	....	6.37 } 13.24	10.35	28.65	+13.24	+10.35	+28.65
Paragonite molecule	....	6.87 }	....	....		....	....
Rutile	....	.43	.47	.81	+ .43	+ .47	+ .81
Apatite	....	1.01	.34	....	....	....	....
Calcite	....	....	....	.60	....	....	+ .60
CuS	....	.35	.45	....	+ .35	+ .45	....
$CuFeS_2$	....	.47	2.84	....	+ .47	+ 2.84	....
FeS_2	....	.83	.95	11.11	+ .83	+ .95	+11.11
H_2O	1.50	2.09	1.26	....	+ .59	− .24	....

1. British tunnel, Last Chance mine, Bingham district; fresh rock.
2. Boston Consolidated mine, Sub. 8, No. 31, crosscut north of drift No. 6; altered rock, "dark porphyry."
3. North end of Pit-Utah copper mine; altered rock, "light porphyry."
4. British tunnel, Last Chance mine, Bingham district; wall of lode.

Analysts: 1 and 2, E. T. Allen (U. S. Geol. Survey Prof. Paper 38, p. 178, 1905); 3 and 4, George Steiger.

It is readily apparent that in all types of wall rock, regardless of the mineralogic changes that resulted, sodium, calcium, and magnesium have notably decreased, silica and alumina have remained nearly constant, and ferrous and ferric iron have remained nearly constant or shown relatively slight decreases. Potassium in every instance shows a notable increase. The total decreases in every comparison are considerably in excess of the total increases, showing that during the alteration there has been a notable loss of mass.

It should be remembered also that the extent of the alteration adjacent to the different types of veins varies notably. In the tourmaline copper veins and the quartz copper veins the alteration is commonly intense for several feet from the wall of the fissure and in many places is pronounced for much greater distances; and in the quartz lead-silver veins, especially in those of the Bingham district, the intensive alteration has extended only to a distance usually measured in inches rather than in feet.

Composition of the solution.—Both the vein minerals and the alteration of the rock adjacent to the veins give an idea of the character of the mineralizing solutions. These solutions, especially those forming tourmaline-quartz veins must have contained iron and carbon dioxide, abundant silica and potassium, and doubtless abundant alumina (though the evidence as to alumina from the tourmaline-quartz veins alone is not conclusive), and abundant boron, as well as sulphur and most of the common metals. That is to say, they were probably alkali-carbonate solutions containing silica, sulphur, and most of the common metals and under certain conditions abundant boron and other constituents.

PHYSICAL CONDITIONS OF DEPOSITION.

The relation of the types is shown in the different districts. In the Clifton district there can be no doubt of the common origin of the quartz-orthoclase-tourmaline-scheelite veins and of the quartz-tourmaline copper veins, and the latter give place to those in which there is little tourmaline and these in turn to veins in which lead is abundant.

In the San Francisco region the close general similarity of the quartz-tourmaline copper and the quartz copper veins gives good reason for attributing a common origin to them. In the Bingham district many points of similarity between the quartz copper veins and the quartz lead veins indicate a common origin. The magnetite-hematite veins do not show so close a similarity or relation to the other types, though many of the copper veins in the Clifton district contain magnetite and specularite in abundance; in fact, if favorably located some could probably be mined for iron flux. The iron-ore veins may be regarded as an extreme type in which iron is especially abundant and copper especially deficient.

The origin of all these veins has already been indicated. The close similarity of the feldspathic tourmaline deposits to true pegmatites seems sufficient evidence for regarding them as having been derived from the differentiation of the same igneous material, and their resemblance to and gradation into other types justifies the belief that all are produced by the same process, the difference in types being due in part, probably in large part, to the physical conditions under which they were deposited. Thus under conditions of high temperature and pressure tourmaline, iron oxides, quartz, and scheelite were deposited, but most of the other metallic constituents remained in solution. With decreasing temperature and pressure copper and finally lead and zinc were successively deposited. As conditions favoring the deposition of a certain mineral were reached the solutions would eventually become deficient in the constituents of that mineral and subsequently would deposit it in decreasing amounts. Thus in the original deposition the metals were roughly separated, iron oxides apparently being deposited under conditions of high temperature and pressure, copper under lower conditions, and lead and zinc under still lower conditions.

If this explanation of the change in types is correct, it would be expected that a space relation would exist indicating the different physical conditions, and this appears to be the case. In the Clifton district this relation has been pointed out. (See p. 482.) In the Bingham district the Bingham Canyon stock, which contains the copper deposits, seems to have been the center of much more intense hydrothermal action than the Last Chance stock, which contains lead deposits. In the Tintic district all the mineralization seems to have been accomplished under moderate conditions. The dif-

ference in the distances from the fissures to which alteration of the wall rock of the different types has extended also points to conditions of decreasing temperature and pressure. It would also be expected that as the igneous activities died out there would be a gradual overlapping of the less intense on the more intense conditions. What appears to be such overlap is seen in the Bingham district, where small lead-zinc veins occupy fissures in copper deposits. The mineralization, however, seems to have been largely accomplished at essentially one time, the deposits formed during the dying stages being small and of relatively slight importance. For further discussion of change in types due to change in temperature see page 184.

DEPOSITS IN SEDIMENTARY ROCKS.

Deposits in sedimentary rocks may be separated into contact deposits and deposits associated with fissures.

CONTACT DEPOSITS.

GENERAL FEATURES.

Contact deposits lie at or near the contact of sedimentary and intrusive rocks and are characterized by the presence of the silicates and other minerals commonly known as "contact minerals," such as garnet, diopside, tremolite, and wollastonite. The contact deposits of commercial importance within the State consist of replacements of limestone and are present in practically every district where limestones are intruded by igneous rock, but they differ greatly in development and have thus far proved of economic importance in but few districts.

The principal metals that have been produced from contact deposits are copper, gold, and silver. There are important contact iron deposits in the State, but these as yet have not been worked extensively for the production of iron, though the iron in some of the copper ores has been utilized as flux and has thus increased the value of the ore.

TYPES OF CONTACT DEPOSITS.

Iron deposits.—Large contact iron deposits occur in the Iron Springs and Bull Valley districts. Deposits containing important amounts of iron, usually accompanied by some copper, exist in the Rocky, Clifton, Little Cottonwood, West Tintic, and other districts, but at present they do not promise to be of importance for the production of iron, though the iron content adds to the value of the ores.

The Iron Springs contact deposits are described in the discussion of the Iron Springs district (see p. 568) and it suffices to state here that they occur as replacements of limestone near quartz monzonite porphyry intrusions. The limestone adjacent to the intrusive has been replaced by albite, kaolin, actinolite, diopside, quartz, orthoclase, serpentine, phlogopite, andradite, iron oxides, andalusite, wollastonite, and other minerals in small amounts. The iron oxides have for the most part been deposited later than the contact silicates. The chemical changes are compared with those of similar deposits on page 173.

Copper deposits.—Contact copper deposits are present in many districts, of which the more important are the Rocky, Beaver Lake, San Francisco, Star, Lincoln, Little Cottonwood, and Clifton. They have been most extensively mined in the Rocky and San Francisco districts. Very closely allied deposits associated with fissures are present in other districts and have been much more important commercially.

The deposits which have the common characteristic of being replacements of limestone and containing the contact minerals garnet, diopside, tremolite, magnetite, and hematite occur irregularly along the limestone intrusive contacts. Long stretches of the contact show only recrystallization of the limestone with very slight replacement, but other stretches show almost complete replacement by silicates and other minerals.

The various deposits differ greatly in their content of the replacing minerals. In some the silicates constitute a large percentage of the material and in others magnetite or hematite is more important. Sulphides are present in greater or less amounts and are apparently about as abundant in some deposits composed largely of silicates as in those in which iron oxides predominate. There are large areas replaced by silicates, however, that contain very little sulphide.

The different minerals were in part formed at the same time, though both sulphides and iron oxides were also deposited after the main replacement of the limestone by silicates, as is

shown by small veins of these minerals cutting the contact silicates. Where sulphides are most abundant they were apparently deposited in large part later than the silicates. The principal original sulphides are pyrite, chalcopyrite, and bornite, and smaller amounts of sphalerite and galena.

In the Clifton and Grouse Creek districts scheelite occurs in contact deposits.

Most of the deposits outcrop prominently, and they have been prospected in many places. The original deposits commonly contain only relatively small amounts of copper, and few of those in which the gangue is principally silicates have proved to be of commercial grade. The heavy gangue minerals have prevented successful concentration by methods dependent on differences in specific gravity. The deposits that contain large proportions of the iron oxides have been successfully mined where transportation costs were moderate, the value of the iron as a flux adding materially to the value of the ore. Such ores have been most extensively mined in the Rocky district.

The alteration of the ores has resulted in local enrichments that have produced "pockets" of relatively high grade material. These have been successfully mined on a small scale but have not been of great importance.

Altogether, the developments on the contact copper deposits have probably been the most unsatisfactory of those on any important type of deposit in the State. Very closely allied deposits associated with fissures have, however, been large producers of copper.

Gold deposits.—Gold and silver are present in small amount in all of the contact copper deposits of the State, but only in the Clifton district in the north end of the Deep Creek Range have contact deposits been developed in which gold is the most important constituent.

The characteristic occurrence is as a replacement of certain beds of Carboniferous limestone near but not necessarily at the contact with intrusive rock. The limestone is replaced by silicates, principally wollastonite with small amounts of diopside, vesuvianite, and garnet, and by sulphides, including chalcopyrite, bornite, and molybdenite, and in at least one place some arsenopyrite.

The sulphides were among the latest minerals to form, being in part at least later than the silicates. The gold is in part free and probably in part associated with the sulphides. In what appears to be unaltered material it occurs between the silicate grains. In some of the richest ore the action of oxidizing solutions is evident and the gold is in part contained in small fissures. Most of the ore treated contained only small quantities of sulphides. Commonly the gold is not uniformly distributed through the replaced limestone but occurs in irregular shoots.

Other contact deposits.—A few deposits have been prospected or mined for metals other than iron, copper, or gold. In the Lincoln district in the Mineral Range there has been a small production of lead from deposits very closely allied to the contact type; and in the Clifton and Grouse Creek districts some prospecting has been done on contact deposits containing scheelite, from which some tungsten has been produced.

CHEMICAL AND MINERALOGIC CHANGES DUE TO CONTACT ALTERATION.

The chemical and mineralogic changes that take place in the contact alteration of the limestone differ greatly in different deposits, though the more important ones show general similarity. Such deposits have been studied in detail in but relatively few districts in the State. There is no sharp distinction between the changes in typical contact alteration and in replacements associated with fissures, though there is usually a mineralogic difference that indicates different physical conditions of formation.

By far the most extensive change along the contacts is a recrystallization of the limestone, usually with relatively slight additions and subtractions, the former probably due to small amounts of material given off directly from the contact. The more intensive changes are far more localized and are apparently due to solutions that have followed the intrusion and at least partial solidification of the igneous material. Such solutions have been directed and concentrated along lines of relatively easy passage.

The following table shows the changes that took place in the marmarization of limestone in the Bingham district:[1]

[1] Boutwell, J. M., Economic geology of the Bingham mining district: U. S. Geol. Survey Prof. Paper 38, p. 180, 1905.

Analyses showing changes in metamorphism of limestone.

[Analyst, W. F. Hillebrand.]

	1	2	3
SiO_2	27.78	27.76	34.36
MgO	.34	6.09	6.09
CaO	39.98	38.91	35.99
CO_2	30.76	24.28	25.91

1. Blue limestone from south slope of West Mountain, on road to Tooele.
2. Slightly marmarized limestone from same locality.
3. Marble from same locality.

The changes have been comparatively slight, the especially notable ones being a slight increase in silica and magnesium and a decrease in calcium and carbon dioxide.

The following tables show the chemical and mineralogic changes that have taken place in the contact alteration of limestone in the San Francisco district:

Analyses of slightly altered and highly altered limestone from the San Francisco district, Utah.

[George Steiger, analyst.]

	1	2	1a	2a
SiO_2	15.44	0.68	37.94	41.04
Al_2O_3	2.78	.18	4.59	13.37
Fe_2O_3	.20	.19	21.09	6.09
FeO	1.00	.27	.41	1.01
MgO	7.62	21.16	1.79	3.32
CaO	35.05	30.78	33.20	31.28
Na_2O	.09	.05	.17	.15
K_2O				.46
H_2O-	.03	.30	.07	.13
H_2O+	1.33		.22	.69
TiO_2	.20	None.	.21	.48
CO_2	35.65	46.65	.17	1.04
P_2O_5	.39	Trace.	.06	.12
SO_3	.06	None.	.08	.14
MnO	.34	.05	.44	1.07
	100.18	100.31	100.44	100.39
Density	2.72	2.84	3.56	3.30

1. Banded crystalline limestone from near Reciprocity mine (specimen 123).
2. Gray dolomitic limestone from east of Reciprocity mine (specimen 121).
1a. Banded rock representing alteration of limestone from near Reciprocity mine (specimen 119).
2a. Massive garnet rock from northeast of Reciprocity mine (specimen 124).

Mineral composition of slightly altered and highly altered limestone from the San Francisco district, Utah.

	1	2	1a	2a
Calcite molecule	62.60	54.90		2.40
Magnesite molecule	15.51	44.97		
Quartz	14.71		1.02	.96
Chlorite	3.74	2.28		
Andradite molecule			67.06	15.24
Grossularite molecule				47.99
Tremolite			7.07	21.40
Vesuvianite			23.49	
Epidote				10.40
Not calculated:				
Al_2O_3	1.43			
Na_2O, K_2O	.09	.05	.17	.61
H_2O	.86		.17	.63
TiO_2	.20		.21	.48
CO_2			.17	
P_2O_5	.39		.06	.12
SO_3	.06		.08	.14
MnO		.05		
			99.50	100.37

The following table shows the increase and decrease of the principal constituents in a given volume of rock. It is assumed that there has been no change in volume during the metamorphism.

Weight of the principal oxides in cubic centimeters of slightly altered and highly altered limestone from the San Francisco district, Utah.

[Grams in 1 cubic centimeter of rock.]

	1	2	1a	2a	Increase (+), decrease (−).	
					1, 1a	2, 2a
SiO_2	0.419	0.019	1.350	1.354	+0.931	+ 1.335
Al_2O_3	.075	.005	.163	.441	+ .088	+ .436
Fe_2O_3	.005	.005	.751	.201	+ .746	+ .196
FeO	.027	.007	.014	.033	− .013	+ .026
MgO	.207	.601	.064	.109	− .143	− .492
CaO	.953	.874	1.182	1.032	+ .229	+ .158
CO_2	.969	1.325	.006	.034	− .963	− 1.291

Figure 28 shows diagrammatically the change in a unit volume in the different constituents on the assumption that there has been no change in volume during metamorphism.

The important chemical changes are evidently additions of silica, alumina, and ferric iron and nearly complete elimination of carbon dioxide. In both analyses magnesia shows a decrease and calcium an increase. Combined calcium and magnesium show a slight increase in one analysis and a decrease in the other. The net result of the additions and subtractions shows a notable increase in the mass.

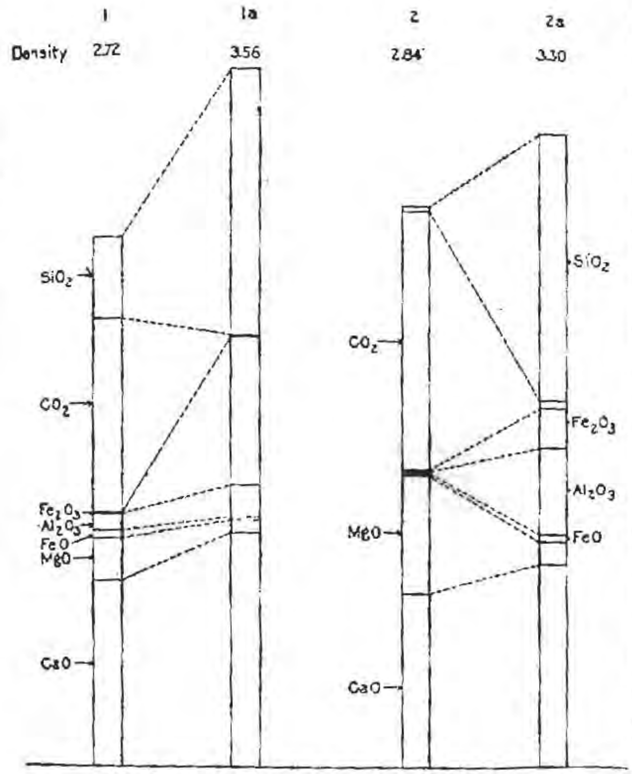


FIGURE 28.—Diagram showing gain or loss in grams of each constituent in the metamorphism of 100 cubic centimeters of limestones in the San Francisco district. Scale, 1 inch=50 grams.

The mineral composition of the metamorphosed limestone is plainly in part dependent on the chemical composition of the original rock.

In the Iron Springs district the alteration of the limestone adjacent to quartz monzonite stocks has been studied by Leith and Harder. The following table of analyses[1] shows the chemical composition of the unaltered and normal types of metamorphosed limestone:

[1] The Iron ores of the Iron Springs district: U. S. Geol. Survey Bull. 338, p. 28, 1908.

Analyses of unaltered and metamorphosed Homestake limestone, Iron Springs district.

[Analyses by R. D. Hall, University of Wisconsin.]

	1	2	3	4	5
SiO_2	8.08	6.90	52.00	57.05	50.73
Al_2O_3	1.95	1.03	9.32	9.86	14.63
Fe_2O_3	.87	1.04	5.08	3.10	11.51
FeO	.06	.75	2.41	1.80	1.13
MgO	2.86	4.52	9.40	8.16	6.36
CaO	46.67	47.15	14.47	8.61	1.24
Na_2O	.13	.13	1.94	4.30	2.02
K_2O	.77	.93	1.41	1.56	4.24
H_2O	1.01	1.04	3.30	3.89	7.03
P_2O_5	.05	.04	.12	.13	.32
CO_2	37.60	36.42	.63	1.74	.21
BaO	None.	None.	None.	None.	.01
	100.05	99.95	100.08	100.20	99.43
Density	2.705	2.706	2.59	2.57	2.22

1. Specimen No. 46319. Unaltered blue limestone from west of Three Peaks.
2. Specimen No. 46375. Unaltered blue limestone from Desert Mound.
3. Specimen No. 46349. Altered limestone between ore and unaltered blue limestone at Desert Mound.
4. Specimen No. 46376. Altered limestone between ore and andesite at Desert Mound.
5. Specimen No. 46338. Altered limestone between ore and andesite on Lindsay Hill.

The following table shows the weight of the principal oxides in a given volume of the unaltered and metamorphosed limestone; and on the assumption that there has been no change in volume during metamorphism it shows the additions and subtractions as in the table for the San Francisco district (p. 170). Leith and Harder, however, do not consider that the volume has remained constant. (See p. 573.)

Weight of the principal oxides in unaltered and contact-metamorphosed Homestake limestone from Iron Springs district.

[Grams in 1 cubic centimeter of rock.]

	1	2	3	4	5
SiO_2	0.2185	0.1867	1.3468	1.4661	1.1262
Al_2O_3	.0527	.0278	.2413	.2534	.3247
Fe_2O_3	.0235	.0281	.1315	.0796	.2555
FeO	.0016	.0203	.0624	.0462	.0250
MgO	.0773	.1223	.2434	.2097	.1412
CaO	1.2624	1.2758	.3747	.2212	.0275
Na_2O	.0035	.0035	.0502	.1105	.0448
K_2O	.0208	.0251	.0365	.0401	.0941
H_2O	.0273	.0281	.0854	.0999	.1560
P_2O_5	.0013	.0010	.0031	.0033	.0071
CO_2	1.0170	.9855	.0163	.0447	.0046

Figure 29 brings out the change in the principal constituents based on the assumption of constant volume. The most important additions are of silica, alumina, ferric iron, magnesium, and sodium. The loss of calcium and of carbon dioxide has been large. The total subtractions are somewhat greater than the total additions resulting in a slight net decrease in the mass.

The following table shows the mineral composition of the unaltered and metamorphosed limestone:

Mineral composition of fresh and altered beds of Homestake limestone, calculated from chemical composition.

Mineral.	Fresh limestones.		Altered limestones.		
	1	2	3	4	5[a]
Calcite	78.30	72.40	1.40	3.90	0.50
Kaolin	4.90	2.58	11.61	3.09	24.77
Chert	2.64	......	1.50	6.30	18.78
Actinolite	......	......	15.55	19.00	......
Diopside	......	......	20.52	4.32	2.16
Phlogopite	......	......	......	......	15.57
Serpentine	......	......	4.97	6.76	5.24
Andradite	......	......	11.20	3.14	......
Magnesite	5.96	8.65	......	......	......
Wollastonite	6.03	9.86	4.76	3.13	......
Albite	......	......	16.24	36.15	16.77
Orthoclase	......	......	8.34	8.89	......
Limonite	1.12	.56	1.31	2.62	3.74
Magnetite	......	.69	......	......	3.48
Hematite	......	......	......	......	5.92
Enstatite	......	1.00	......	......	......
Apatite	......	......	.31	.31	.62
Pyrite	.12	.84	......	......	......
Water	.16	.59	.81	2.21	1.54
Siderite	......	......	......	......	......
Witherite	......	......	......	......	......
	99.23	97.17	98.52	09.82	99.09

[a] Contains glass which has been calculated in terms of minerals.

The most notable difference in the alterations in the Iron Springs and San Francisco districts, as shown by the analyses, is the large decrease in calcium and the increase in sodium in the Iron Springs district, and the relative smallness of the change in those constituents in the San Francisco district; also, the slight decrease in the density of the resultant rock in the Iron Springs district, and the corresponding notable increase in the San Francisco district.

A type of contact alteration that is present in some districts consists of the addition of abundant silica and some iron, resulting in masses of cherty quartz, some of which contain enough iron to give them a jasperoidal character. Such bodies are present in the Clifton district and in places along the Tintic contact zone. Enstatite and spinel are the most abundant contact minerals in the Tintic district.

In other districts the contact metamorphism has added elements that are not common to all the deposits. Thus boron has been added in forming tourmaline in the Clifton district and in forming ludwigite in the Big Cottonwood district.

VOLUMETRIC CHANGES DUE TO CONTACT METAMORPHISM.

The volume relation that exists between an unaltered limestone and its contact metamorphosed equivalent, especially where the contact facies consists largely of silicates, is a subject over which there has been much discussion and one on which a general agreement has never been reached. By some it is held that during the metamorphism there has been no important change of volume in the rock mass, and that the differences in composition have been due largely to the addition of silica, ferric iron, and alumina and the removal of carbon dioxide and to lesser changes in other constituents. By others it is held that there has been a large shrinkage in the volume of the original body, owing to the removal of certain constituents, mainly carbon dioxide and calcium, and that the change in composition is due in large part to a concentration of certain elements of the original rock—a concentration that might be compared in result to the relatively small residuum of clay derived from the weathering of limestone. By this process the change is regarded as due chiefly to removal of certain constituents, although it is recognized that additions have played some part in the change—and in the case of metallic constituents an important part. The literature on the subject has been reviewed by Uglow[1] and in textbooks, notably by Lindgren.[2]

Where deposits are adjacent to large intrusive masses it is usually difficult to ascertain positively whether or not there have been important changes in volume during metamorphism, though Umpleby[3] has secured convincing evidence of essential constancy of vol-

[1] Uglow, W. L., A review of the existing hypotheses on the origin of the secondary silicate zones at the contact of intrusives with limestones: Econ. Geology, vol. 8, pp. 19-50, 215-234, 1913.

[2] Lindgren, Waldemar, Mineral deposits, p. 669, 1913.

[3] Umpleby, J. B., The genesis of the Mackay copper deposits: Econ. Geology, vol. 9, pp. 307-358, 1914.

ume in the Mackay deposits in Idaho. Where replacement has occurred at some distance from intrusive bodies, especially in closely allied deposits associated with fissures, opportunities for determination are far more favorable.

In the contact gold deposits of the Clifton district certain beds of limestone for considerable distances along the strike and dip have been converted largely to wollastonite without any appreciable change in volume. In the Mineral Range at the "Bismuth mine," several hundred feet from any large body of intrusive rock, a bed of limestone for a considerable distance along the strike has been largely con-

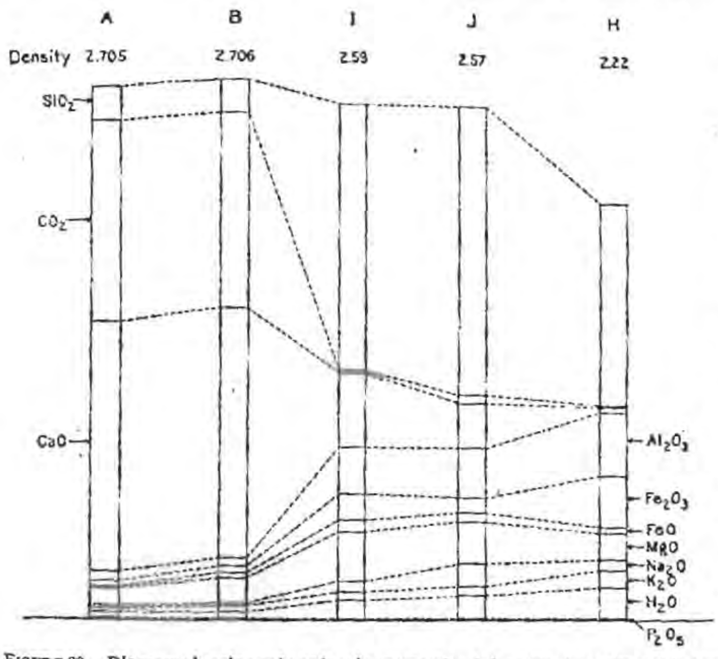


FIGURE 29.—Diagram showing gain or loss in grams of each important constituent in the contact alteration of 100 cubic centimeters of the Homestake limestone, Iron Springs district.

verted to garnet and other silicates without appreciable change in volume. In the Ophir Hill mine in Ophir district the limestone strata in the shale adjacent to fissures have been in places (see Pl. XXXVII, *A*, p. 376) largely converted to silicates and to sulphides without destroying the details of the bedded structure of the limestone and without showing any indications of important change in volume. In the Deertrail mine near Marysvale a stratum of limestone over a considerable area has been largely replaced by muscovite (sericite) without apparent change of volume; the alteration is adjacent to a fissure and only small dikes of intrusive rock later than the alteration of the limestone are present. In every occurrence seen by the writer in which the evidence seemed conclusive no change in volume was apparent, and in numerous occurrences in which the evidence could not be regarded as conclusive the relations were most readily explained by the supposition of essential constancy in volume.

RELATION OF CONTACT DEPOSITS TO DEPOSITS IN INTRUSIVE ROCKS.

The solutions producing the deposits in the intrusive rocks contained abundant silica and iron and some alumina, as well as sulphur and most of the common metals; and the solutions effecting the contact metamorphism of the limestone contained essentially these same constituents. The similarity in these solutions is most strikingly shown where they contain some unusual constituent. Thus in the Clifton district the abundance of tourmaline in both types of deposits indicates that boron was an important constituent in both solutions, and the presence of scheelite in small amounts in both types indicates that tungsten also was present in both. In the Iron Springs district the deposition of albite in both types is a notable feature. These close similarities in the composition of the solutions naturally lead to the belief that the two had a common origin and that the differences in the character of the deposits are due largely to the differences in the character of the rocks on which they acted.

Too close likenesses can not be expected in the two types, but some interesting comparisons are possible. In the Iron Springs district the magnetite-hematite veins within the intrusive rocks correspond to iron deposits in the contact zone, and in the Clifton district the tourmaline-quartz copper veins with abundant iron oxides find their counterpart in tourmaline iron-copper contact deposits. Even the wollastonite contact gold deposits of the Clifton district find their counterpart in the quartz gold deposits in the intrusive rocks, as do also the contact jasperoidal masses in the silicified zones in the intrusive rocks. Similar relations have been pointed out in the San Francisco and adjacent districts and less notable ones in other districts.

It is believed, therefore, that the solutions producing the two types of deposits had a common origin.

GENESIS OF THE CONTACT DEPOSITS.

If the solutions forming the contact deposits and the deposits in the intrusive rocks had a common origin, they resulted from differentiation of the magmas that formed the main intrusive bodies, as has been pointed out in the discussion of deposits in intrusive rocks. The contacts of the intruded and intrusive rocks were favorable localities for the passage of solutions, and where conditions favored the concentration of solutions from deep-seated sources large masses of limestone were metamorphosed. In the Little Cottonwood district aplitic and pegmatitic dikes are very abundant in the intrusive body adjacent to large areas of contact-altered limestone, strongly suggesting that they now fill the channels through which the metamorphosing solutions passed from the igneous body into the adjacent sedimentary rocks.

DEPOSITS ASSOCIATED WITH FISSURES.

SELECTIVE DEPOSITION.

Deposits in or adjacent to fissures in sedimentary rocks have to the present time been the most productive in the State. Most of them occur as replacements of sedimentary rocks, commonly limestone, adjacent to the fissures, though some occur in breccia zones and in fissures in siliceous rocks. The most notable of the deposits in siliceous rocks is that in the Ontario fissure in the Park City district.

Influence of the chemical composition of rocks.—Selective replacement of especially soluble beds has been observed in many districts. In the Bingham district, where the great ore bodies in the sedimentary rocks occur in large part as a replacement of relatively small bodies of limestone interstratified with the great quartzite series, there can be no doubt of this selective action. In the Ophir district, deposits that are mainly replacements of limestone in a series composed predominantly of shale and underlain by massive quartzite show a similar selective action. In the Stockton district a remarkable regularity in the mineralization where certain limestone beds are intersected by mineralizing fissures is apparently due to the composition of the limestones. The following partial analysis shows the composition of the limestone of the Honorine mine, locally called "Honorine limestone," one of the most important ore-bearing beds of the district, in comparison with that of the overlying "dolomite." The highly siliceous beds are apparently much less susceptible to replacement than the rather pure limestone. The underlying bed is apparently similar in composition to the overlying.

Partial analysis of the limestone of Honorine mine and of the overlying "dolomite."

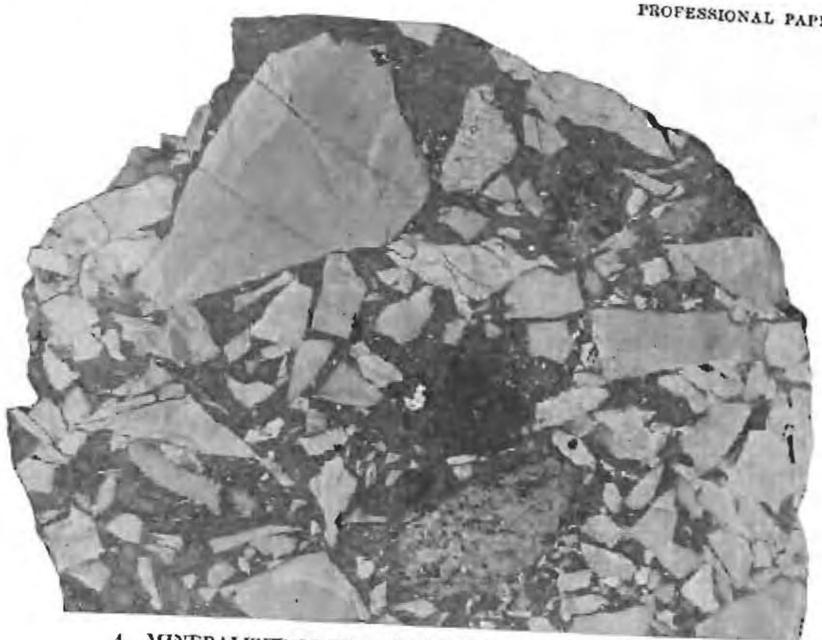
[By R. C. Wells.]

	Honorine limestone.	White dolomite.
SiO_2	2.39	42.12
CaO	53.85	29.20
MgO	.53	7.29

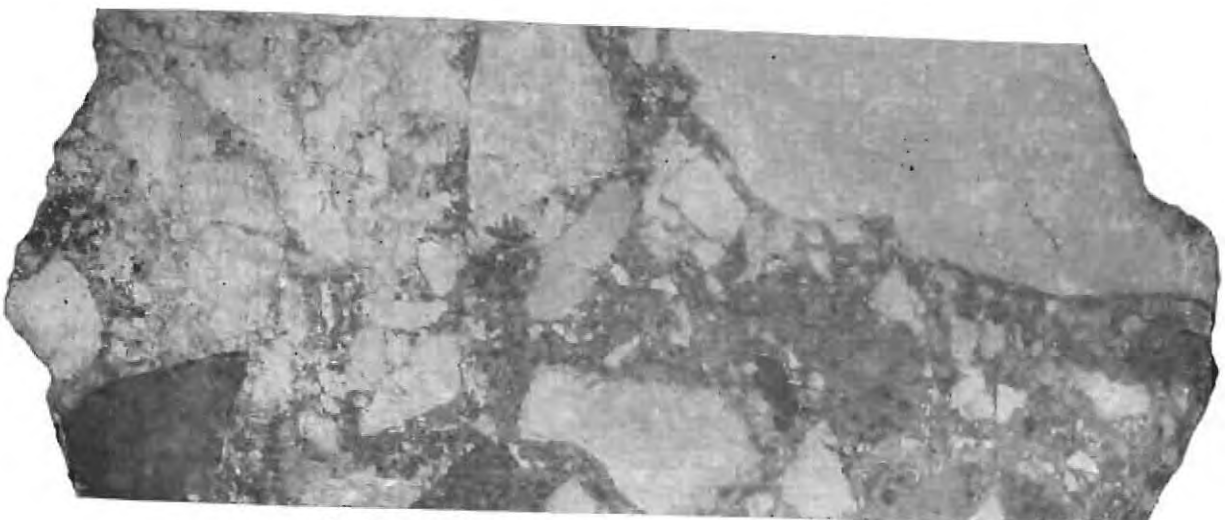
Boutwell has shown that in the Park City district replacement occurs in beds composed essentially of calcium and magnesium carbonate and very low in silica and does not affect highly siliceous overlying and underlying beds. Similar conditions exist in the Tintic district, where the larger ore bodies replaced limestones or dolomites with a relatively low silica content, whereas adjacent beds higher in silica and more dense in texture were only slightly replaced. The same is also true of certain limestone beds in the Little Cottonwood district, notably that locally known as the "Flagstaff limestone," which is one of the main ore-bearing beds of the district. (See fig. 30.) Conditions in many other localities indicate that rocks composed essentially of carbonate are especially susceptible to replacement by metal-bearing solutions.

In some places minor constituents have probably helped to precipitate the metals, beds containing them having been more favorable to deposition than the carbonate beds. Thus, the gold deposits of the Mercur district occur mainly in shaly beds, although they are overlain by limestones and underlain by other limestones that have been extensively replaced by silica. Apparently the shales were especially favorable for the precipitation of the gold.

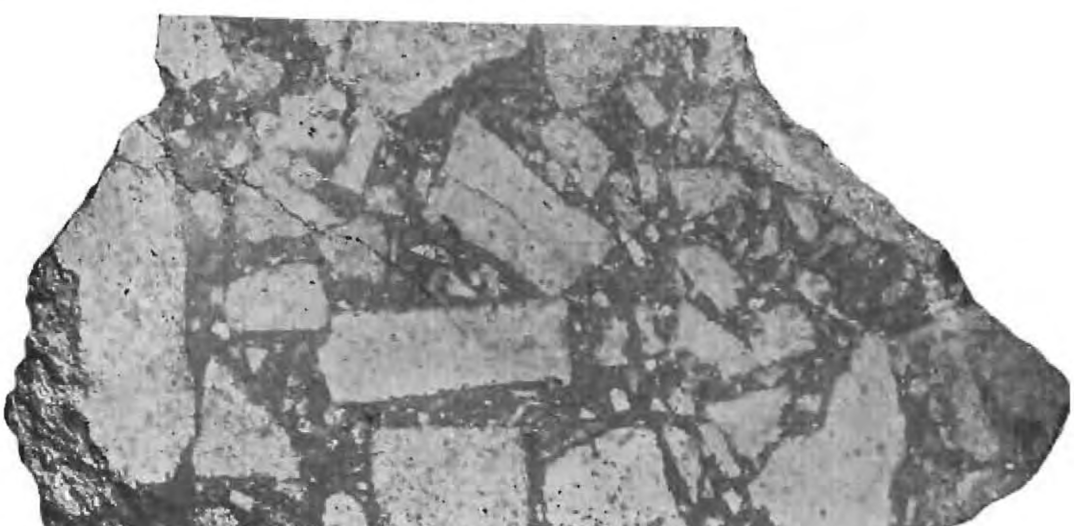
Influence of physical conditions of rocks.—Physical conditions that are especially favor-



A. MINERALIZED LIMESTONE BRECCIA, OLD EMMA MINE.
Photograph by F. B. Laney.



B. MINERALIZED LATITE BRECCIA, HORN SILVER MINE.

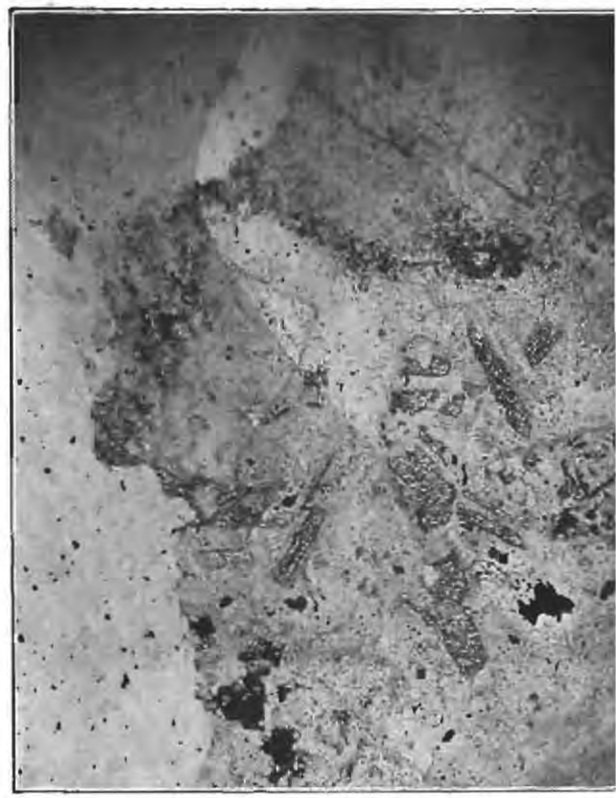


C. MINERALIZED QUARTZ MONZONITE BRECCIA, CACTUS MINE.

BRECCIA ORES.

A. PHOTOMICROGRAPH OF SPECIMEN OF ORE FROM GOLD SPRINGS DISTRICT, SHOWING REPLACEMENT OF CALCITE BY QUARTZ AND ADULARIA; LATH-SHAPED BODIES PARTLY REPLACING CALCITE CRYSTALS.

Enlarged 30 diameters.



B. PHOTOMICROGRAPH OF SPECIMEN OF ORE FROM M DISTRICT, SHOWING REPLACEMENT OF BARITE BY QU ADULARIA.

Rough areas, barite. Enlarged 30 diameters.

C. PHOTOMICROGRAPH OF SPECIMEN OF VEIN MATERIAL FROM GOLD SPRINGS DISTRICT, SHOWING QUARTZ AND ADULARIA.

Rough areas, adularia. Enlarged 30 diameters.

able to the concentration of solutions along certain channels are of course favorable to the deposition of ores.

Brecciation along fissures and slight movements along bedding have produced conditions favorable to mineralization. (See Pl. XVII.) Very commonly certain beds in a series brecciate much more readily than the others, and where a fissure cuts such a series of beds a strong breccia zone follows the intersection of the fissure and the easily brecciated bed. This forms a favorable place for deposition of ore. Such conditions are well illustrated in the Little Cottonwood district. Overthrust faulting also forms breccia zones

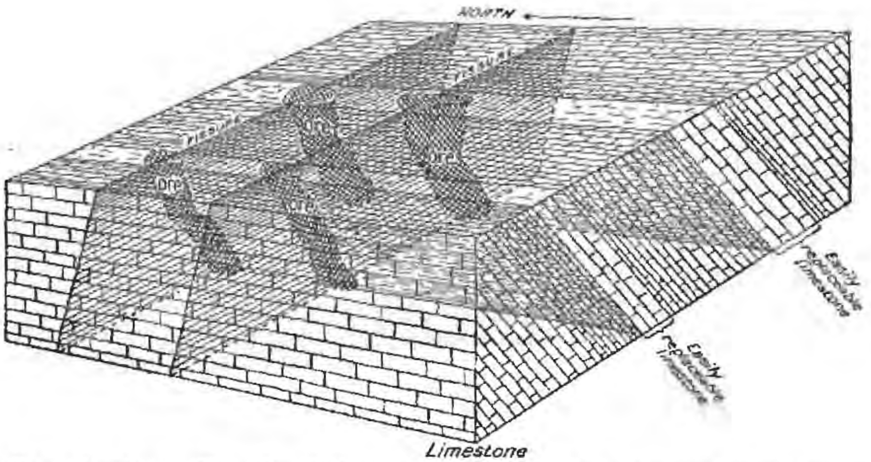


FIGURE 30.—Diagram illustrating selective replacement of certain beds of limestone adjacent to fissures.

that favor ore deposition, as is shown by several deposits in the Cottonwood area.

It has long been recognized that fissures passing through shales become "tight" and relatively impervious, and that in many places solutions rising along them spread out beneath the shales and deposit their metal content. Localization of deposits due to this cause have been noted in the Star district and elsewhere.

Dikes and sills of igneous rock have in some places apparently exerted a similar influence. Such appears to have been the case in the Fish Springs district, probably in the Lion Hill section of the Ophir district, and possibly to some extent in the Mercur district.

Many prospectors consider the contact of quartzite with limestone or some other rock to be especially favorable to ore deposition, and some of them have expended much effort and money in exploring such contacts, but the results have frequently been disappointing. The distribution of developed ore bodies in the Park City, Bingham, Tintic, and Ophir districts, all of which contain large quantities of quartzite, gives no support to the idea that ore is especially likely to occur at the contact of quartzite with another kind of sedimentary rock if the contact is the result of normal sedimentation. But the fact that normally superposed formations commonly intergrade establishes a slight presumption that the contact of two sharply contrasted rocks, like limestone and quartzite, is due to faulting. The limestone that is brecciated along such a fault is likely to be permeated and in part replaced by any mineralizing solutions that may find access to it; and some important ore bodies, such as those along the thrust contacts of limestone and quartzite in the Little Cottonwood district, have been formed in this way. Quartzite contacts, then, should not be explored on the blind assumption that they are somehow favorable; but they may sometimes repay judicious exploration guided by knowledge of the physical and chemical factors that favor the deposition of ore.

CLASSIFICATION BY METALS.

Deposits in the sedimentary rocks associated with fissures, like deposits in the igneous rocks, can be grouped according to the metals for which they are chiefly valuable. As in the igneous rocks, these groups usually grade into each other, so that, though most deposits are valuable for one metal or group of metals, others are intermediate and contain important amounts of several.

Copper deposits.—Copper deposits of this type have been most extensively developed in the Bingham district, though they are present in other districts, notably in the Lucin and less notably in the Star district, and may be considered to include some of the deposits of the Tintic district, which commonly have their greatest values in precious metals rather than in copper.

Most of the deposits have formed very largely as a replacement of limestone, though a few of them occupy fissures. An exception is found in the mines of the Ohio Copper Co., at Bingham, where the ores occur along fissures in quartzite. The great majority of the deposits in the sedimentary rock, however, are replacements of limestone, as, for instance, in the Highland Boy, Commercial, Boston Consolidated, and Yampa, and in certain sections of the Old Jordan and other mines in the Bingham district.

The mineralogy of the primary ores shows considerable variation in different districts and even in the same district. In the Bingham district the prevailing gangue mineral, aside from unreplaced country rock, is quartz, though garnet and other "contact" silicates are commonly present in small amounts and locally are so abundant that the deposits resemble true contact deposits. The prevailing primary metallic minerals are pyrite and chalcopyrite, though locally hematite is abundant, as in parts of the Highland Boy mine, and other sulphides are present in small amount. Oxidation processes have been an important factor in the enrichment of the upper parts of most of the Bingham deposits.

The copper deposits of the Star district, though similar in character to those of the Bingham district, are of relatively slight importance. Some of the deposits in the Beaver County region resemble and grade into contact deposits.

The principal deposits of the Lucin district are entirely oxidized so far as developed, and the primary mineralization can only be inferred. The abundance of limonite suggests that iron sulphide was an important primary mineral, and it is probable that the copper was mainly present as chalcopyrite.

The deposits of the Tintic district, in which copper is an important constituent, differ somewhat from those in the other districts in that the precious metals are more important and the primary copper mineral is enargite. Fine-grained quartz and barite are the common gangue minerals, but garnet and allied deep-vein silicates are absent.

Lead-silver deposits.—Lead-silver deposits in sedimentary rocks have so far been the most productive type in the State. They furnished most of the "bonanzas" of the early days of mining, and they have yielded steadily and largely ever since. They are altogether lacking in but few of the districts in the State where limestones have been intruded by granitic stocks, but they are most important in the zone extending from Park City to the Oquirrh Range and in the Tintic Range. Districts in which large deposits of this type have been developed include the Park City, Little Cottonwood, Big Cottonwood, American Fork, Bingham, Stockton (Rush Valley), Ophir, Tintic, and Star districts, and small deposits are present in many other districts.

The occurrence of the lead-silver deposits is in general similar to that of the copper deposits, into which they grade. Most typically they occur as replacements in limestones adjacent to fissures, but they also occupy fissure veins, notably in the great Ontario lode of the Park City district.

The prevailing gangue mineral is quartz in all deposits, but other minerals are important in certain districts, as barite in the Tintic district, muscovite (sericite) in the Park City, Little Cottonwood, Bingham, Marysville, and other districts, and orthoclase in some of the replacement deposits of the Ophir district. In the Star district and in the Mineral Range some of the deposits contain rather abundant garnet and diopside and show transition to the contact type. In the primary ores lead is commonly present as galena, usually argentiferous, and silver is present to some extent in other sulphides. Pyrite is rather abundant, and sphalerite ranges from very little to as much or more than galena. Copper is commonly present in small amounts—as tetrahedrite in the Park City and Cottonwood districts, as enargite in the Tintic district, or as chalcopyrite in the Star, Bingham, and other districts. Other metallic minerals are present in small amount. The ores usually contain relatively little copper or gold, but in the aggregate they yield a considerable quantity of both these metals.

Most of the deposits are extensively oxidized, and in several districts the development of the primary ores is slight; in others, however, notably the Park City and Bingham districts, the production from these ores has been large.

Zinc-silver-lead deposits.—In several districts the original deposits contain, in addition to lead and silver, valuable amounts of zinc in the form of sphalerite; in other localities important bodies of zinc ore have been segregated during the process of oxidation. (See p. 211.)

Primary ores containing commercial amounts of zinc have been developed in the Park City and Bingham districts, and to a lesser extent in the Ophir, Stockton, and Star districts; and oxidized zinc ores have been mined in the Tintic, North Tintic, Ophir, and Star districts. The occurrence of the original ores is in every way similar to that of the lead-silver ores, and there is every gradation from ores containing little sphalerite to those from which zinc is commercially recoverable.

Silver deposits.—In some deposits the silver content is so large that the ores are essentially silver ores, although all of them contain some lead, zinc, and copper and usually a little antimony and arsenic. Important deposits of this type occur in the Lion Hill section of the Ophir district and lesser deposits in the Marysvale region in the Star, Silver Islet, and other districts. Some of the rich silver ores from the Ontario mine of the Park City district may be assigned to this type. The general occurrence and character of these deposits differs in no wise from the lead-silver deposits except in the relative proportion of the different metals.

Gold deposits.—Although gold in small amount is present in practically all of the deposits in the sedimentary rocks associated with intrusive rocks, deposits in which gold is the principal valuable constituent are rare. The only deposits of this type that have yielded a large amount of gold are those of the Mercur and adjoining Sunshine and West Dip districts. Deposits in which gold is the most valuable constituent are present in the Deertrail mine in the Marysvale district. Some gold ores also occur in the Tintic district, where the gold forms microscopic and occasionally megascopic grains in chalcedonic quartz.

The gold deposits in the Mercur and adjacent districts have been described (see p. 392), and it is here only necessary to state that the ore occurs in the sediments adjacent to fissures. Both limestone and shale have been converted to ore, though the shale appears to have been more favorable than the limestone to the deposition of the gold.

In the alteration of the rocks, and especially of the limestone, adjacent to gold veins there has been a notable addition of silica, and the abundance of potassium in some of the ores suggests that it also has been added in important amounts. Barium has been added to the form of barite. The principal metallic minerals are pyrite, realgar, and cinnabar in small though locally important amounts. In the Deertrail deposit there have been large additions of silica, alumina, and potassium. Certain strata of limestone have been replaced over considerable areas by muscovite and quartz. Pyrite and galena rich in silver are also present.

Quicksilver deposits.—Deposits of quicksilver in the sedimentary rocks have been developed in but two districts, in neither of which they have been of large commercial importance.

In the Mercur district a small amount of cinnabar occurs in the gold ores, and in certain shoots in the Sacramento mine it was sufficiently abundant to permit its commercial extraction. The general occurrence of the ore is similar to that of the other ores.

In the Marysvale district a small body of quicksilver ore, developed in the Lucky Boy mine near the Deertrail mine, occurs as a replacement of limestone adjacent to fissures. The chief gangue mineral aside from the limestone is barite, and the metallic minerals are tiemannite and onofrite. Quicksilver is also said to be present in small amount in the Deertrail mine.

GENESIS OF THE DEPOSITS.

The mineralogic similarity of deposits in sedimentary rocks associated with fissures to typical contact deposits and the gradations of the one into the other are especially striking in certain deposits in the San Francisco and Star districts and in the Mineral Range but are present in the Bingham, Tintic, Clifton, Little Cottonwood, and other districts. Some of the mineralogic gradations between typical contact deposits and typical hydrothermal replace-

ment deposits are so complete that there can be no doubt of the common origin of the two types, and it seems reasonable and natural to assign a similar origin to others where the gradation is less complete or absent, provided there is no evidence opposed to such an explanation.

The general composition of the mineralizing solutions, so far as can be judged from the minerals they have formed, leads to the same conclusion. In the contact alteration of the limestones there were large additions of silica, alumina, and iron, in addition to sulphur and metallic elements, and the same elements were added to the deposits associated with fissures.

In all the deposits of this type silica was added in large amount. In many of these deposits a considerable quantity of alumina was added as sericite, as is well shown in the ores of the Deertrail mine and in those of the Park City and Little Cottonwood and to a less extent in those of other districts. Abundant alumina must have been added in the formation of the Copper Mountain deposits of the Lucin district and in the replacement of the limestone by feldspar and epidote in some of the deposits of the Ophir district. That potassium was a constituent of the solution producing the mineralization is indicated by the presence of sericite in most deposits and of feldspar in some deposits, as those of Ophir Hill. In all the deposits iron, in the form of sulphide and more rarely as oxide, is abundant, indicating that the solutions were rich in iron and that other metallic constituents were present in various amounts.

It is evident, therefore, that the mineral composition, the character of solutions, and the geologic relations all offer the strongest evidence that the contact deposits and the replacement deposits in the sediments adjacent to fissures were of common origin.

Differences in deposits in a given district are believed to be due in large part to the different physical conditions under which they were formed. Differences in deposits in more widely separated areas may be due to differences in the original character of the solutions.

It is evident that when an area of sedimentary rocks is intruded by igneous material there is a progressive change in physical conditions from the contact outward, and it is to be expected that these differences will be recorded in the changes produced in the rocks. These changes are probably due in greater part to the agency of solutions that are expelled from the magma in the form of hot gases under high pressure. The gaseous solutions thoroughly permeate the rocks for only a short distance from the contact, but they penetrate much farther along fissures and other avenues of easy passage. Wherever they penetrate without losing their high temperature they react with the constituents of the sedimentary rocks to form characteristic contact minerals, such as garnet, diopside, tremolite, tourmaline, and other silicates, magnetite, hematite, copper, and iron sulphides, and other metallic minerals in lesser amount. Commonly, copper and iron are the metals most abundantly deposited.

At greater and greater distances from the intrusive mass the temperature and pressure decrease more and more, the solutions condense to the liquid form, and the alteration in the adjacent rocks changes accordingly. Silicification and in some places sericitization takes place instead of the formation of "contact" silicates; lead, zinc, silver, arsenic, and antimony minerals are more abundantly deposited, and the deposition of copper materially decreases.

In the Tintic district Lindgren [1] finds that the limestone has been replaced by fine-grained quartz that he regards as having been originally deposited largely as gelatinous silica. The veins in the intrusive rocks also indicate formation at moderate to rather low temperatures. The similarity in composition of the veins in the monzonite and the deposits in the sediments and the actual tracing of one vein across the contact point to a common origin for the solutions. The deposits also show, with distance from the intrusive rocks, a progressive change from those containing considerable copper and gold to those having their chief value in lead and silver. At still greater distances the quartz-barite gangue gives place to carbonates and the silver content of primary ore tends to decrease.

It is apparent that as a solution moves outward, depositing some of its constituents and taking up others, it must constantly change in composition, and this, as well as the changing physical conditions, must influence the charac-

[1] Lindgren, Waldemar, Processes of mineralization and enrichment in the Tintic district: Econ. Geology, vol. 10, pp. 225-240, 1915.

ter of the deposits at different distances. It is also evident that as a region gradually loses its heat the temperature at a given place will decrease, and deposits formed at lower temperature will be superimposed on those previously formed at higher temperature. For further discussion see page 184.

DEPOSITS IN EXTRUSIVE ROCKS.

DISTRIBUTION AND CHARACTER.

Deposits in extrusive rocks are of less importance in Utah than in the neighboring States of Nevada and Colorado and are of much less importance than the deposits in the intrusive or sedimentary rocks of Utah itself. They occur in lavas of rhyolitic, latitic, or dacitic composition. They have been found much more frequently in rather massive flows than in tuffaceous rocks, a fact that may be due to the more ready fracturing of the flows. The most extensive deposits of the type are in the southern zone of mineralization, notably in the San Francisco, Gold Springs, and State Line districts, and in the districts of the Tushar Range. Such deposits are also present in the Tintic district but have not been shown to be of commercial importance there.

The deposits commonly have their greatest value in the precious metals, though they have yielded notable amounts of lead, copper, and zinc. The base metals are especially abundant in the deposits of the San Francisco district but are important in some of the deposits of the Tushar Range also.

CLASSIFICATION BY METALS.

On the basis of metal content deposits in extrusive rocks may be subdivided into silver-lead-zinc-copper deposits, gold-silver deposits, and alunite deposits, though some of them, notably those in the Tushar Range, grade from those containing the base metals in abundance to those in which the precious metals are the more valuable.

SILVER-LEAD-ZINC-COPPER DEPOSITS.

Deposits in which lead, zinc, and copper are important have been most productive in the San Francisco district, where the Horn Silver mine has yielded them in large quantity, and the Beaver Carbonate mine has yielded lead, zinc, and copper. Silver is a very important constituent in both of these deposits but gold is very sparingly present. In the Tushar Range numerous mines contain lead, zinc, and copper, though none has produced them in important amounts.

The ore and gangue minerals and altered wall rock adjacent to the veins show considerable differences in different deposits. In the Horn Silver deposit the principal primary metallic minerals are pyrite, galena, sphalerite, chalcopyrite, and possibly other copper minerals, jamesonite or some closely allied antimony mineral, and some undetermined arsenic mineral. The gangue minerals are mainly cherty quartz, barite, and the minerals composing the altered wall rock. In the Beaver Carbonate mine arsenic and antimony minerals and barite have not been recognized and calcite is a gangue mineral. In the Tushar Range tetrahedrite is commonly the principal copper mineral in deposits that contain important amounts of the base metals. Carbonate, commonly containing iron and manganese, is abundant, and barite is present in small amount.

In the Horn Silver deposit the wall rock is intensely silicified. In the early stages of the alteration sericitization is the characteristic change, but there is a progressive removal of all the original constituents except silica and probably iron till the more intensely altered rock consists principally of cherty quartz containing crystals of pyrite. In the Beaver Carbonate deposit the alteration has been less intense, sericite, kaolin, chlorite, calcite, and probably some secondary orthoclase having been formed. The mineralogic changes have been more extensive than the chemical, for none of the original constituents, except possibly sodium, has been notably removed. In the Tushar Range the characteristic alterations are sericitization and silicification.

Important deposits of base metals are not abundant in the Tertiary lavas.[1] Those of the San Juan region, Colo., are the most important in the United States and exhibit many similarities to the deposits in Utah.

GOLD-SILVER DEPOSITS.

Deposits in which gold and silver are the chief valuable metals have been most extensively developed in the Tushar Range and along the Utah-Nevada line, the State line, Gold Springs, and Fay districts.

[1] Lindgren, Waldemar, Mineral deposits, p. 496, 1913.

Typically the deposits are fissure fillings, many of which have a distinct crustified structure. Some show a well-defined wall and some have the vein matter "frozen" to the wall. In neither does the wall rock adjacent to the veins contain more than small amounts of the precious metals and rarely, if ever, is it of commercial value.

Some veins, as those in the districts on the Utah-Nevada line, are very persistent along the strike, outcrops having been traced with considerable certainty for 2 or 3 miles. Other veins, as some of those in the Tushar Range, are very short. In vertical extent also they appear to show a similar variation. Some veins that have been explored to a depth of several hundred feet show no notable change in width, but others change in less than 100 feet below the outcrop into small stringers in a zone of altered rock. Within the State few developments on this type of deposit have been carried below 400 or 500 feet, so that general statements concerning their behavior in depth are not warranted.

The vein fillings of the different deposits resemble each other and also those of corresponding deposits in adjacent States. Typically they consist of fine-grained quartz, calcite, and orthoclase (adularia), with some barite, fluorite, and other minerals. In different veins or in different parts of the same vein any one of these minerals may predominate.

The earliest minerals to form were carbonates, and in some veins of the Tushar Range barite. The carbonates vary in composition from those that are essentially calcite to those containing abundant iron and manganese, these metals being especially notable in veins near Modena, at the Escalante mine, and at the Dalton vein in the Tushar Range. The carbonate has in many places been partly or wholly replaced by quartz or by quartz and adularia. (See Pl. XVIII.) The forms and structures of the earlier minerals were preserved in many places as pseudomorphs, giving the ore a peculiar and characteristic lamellar or hackly structure.

The minerals present in these replacements differ markedly. Much of the carbonate has been so completely replaced that its earlier presence can only be recognized by the forms preserved. Quartz is everywhere abundant where the carbonate is replaced; adularia is in places absent and in places as abundant as the quartz. The quartz is fine grained and much of it is chalcedonic. The feldspar is predominantly potassic but in places contains considerable soda, as in the Jennie vein in the Gold Springs district, where it contains about 20 per cent of the albite molecule. Fluorite has been noted from numerous localities but is important in few of them.

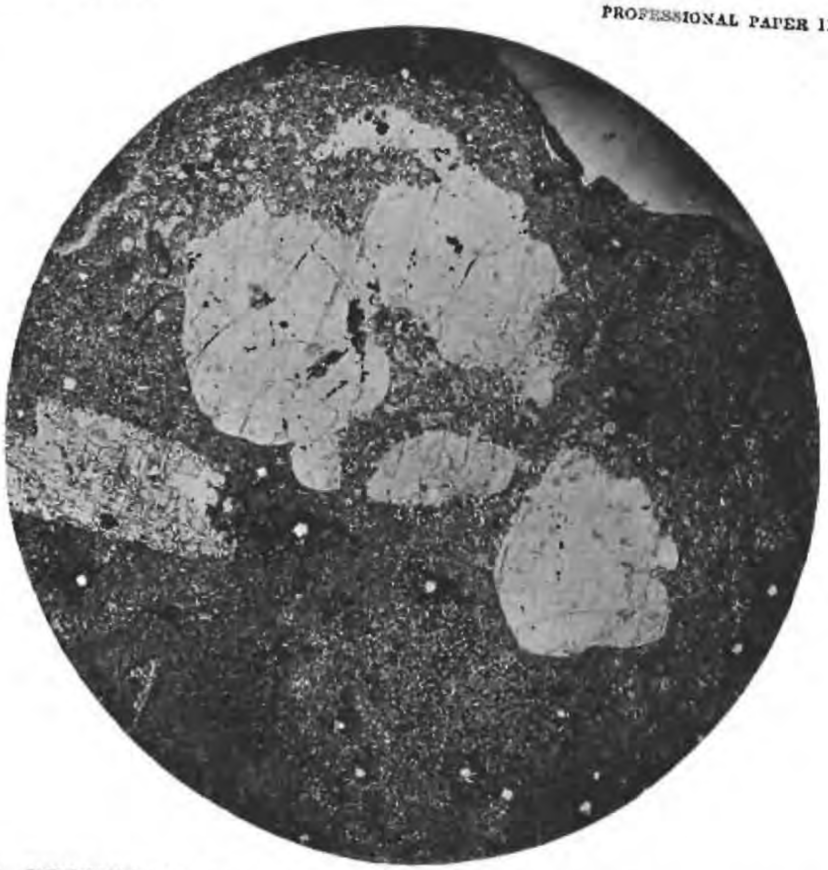
In metallic constituents the veins range from those in which the base metals are nearly absent to those in which they are relatively abundant. Pyrite is nearly everywhere present and is locally rather abundant. Lead and zinc are relatively abundant and arsenic and nickel are present in small amounts in the Escalante vein. Copper and antimony in the form of tetrahedrite are present in considerable quantity in some of the veins of the Tushar Range. Mercury has been recognized in the veins of the Gold Springs–State Line area and may be present at other localities.

The only primary gold-silver mineral noted by the writer is a silvery-white mineral carrying selenium and tellurium and containing fissures filled with pale gold that has probably resulted from its alteration. Sulphide of silver is reported from the Annie Laurie mine. The greater part of the gold occurs as free gold and much of the silver thus far extracted has been the chloride, cerargyrite. Possibly the gold as well as the cerargyrite is secondary in origin.

The veins differ greatly in their gold and silver content. Some are essentially gold veins, others essentially silver veins, and still others contain gold and silver in all proportions. Sharply contrasting veins occur in the same district. The causes of these differences are unknown.

The metallic constituents are segregated in the veins in irregular shoots, many of which constitute only a small part of the vein and are with difficulty found and followed. This has prevented the profitable exploitation of some veins that are known to be ore bearing.

The minerals formed in the wall rock differ greatly in different localities. In the Gold Springs and State Line districts the extensive alteration consists chiefly in the replacement of the country rock by a fine-grained mixture of quartz and orthoclase which constitutes a resistant rock that causes the veins to outcrop prominently. (See Pl. XIX.) To a lesser

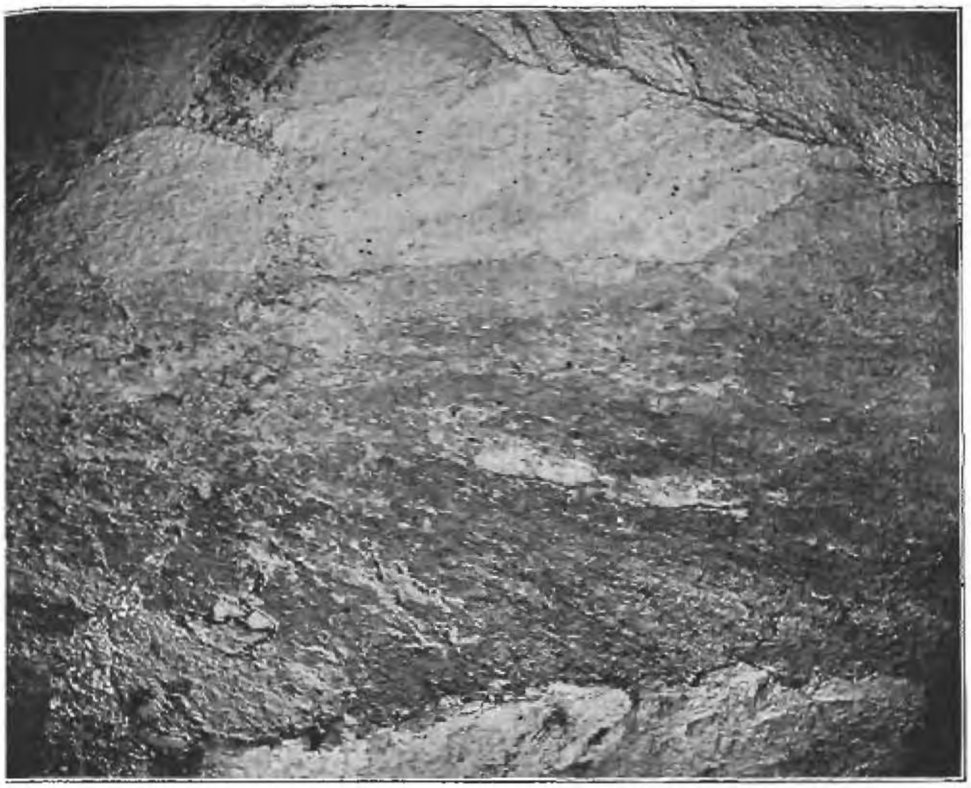


A. PHOTOMICROGRAPH OF SPECIMEN SHOWING ALTERATION OF WALL ROCK ADJACENT TO GOLD VEINS IN GOLD SPRINGS DISTRICT.

Quartz and feldspar crystals partly replaced by quartz and adularia. Enlarged 30 diameters.

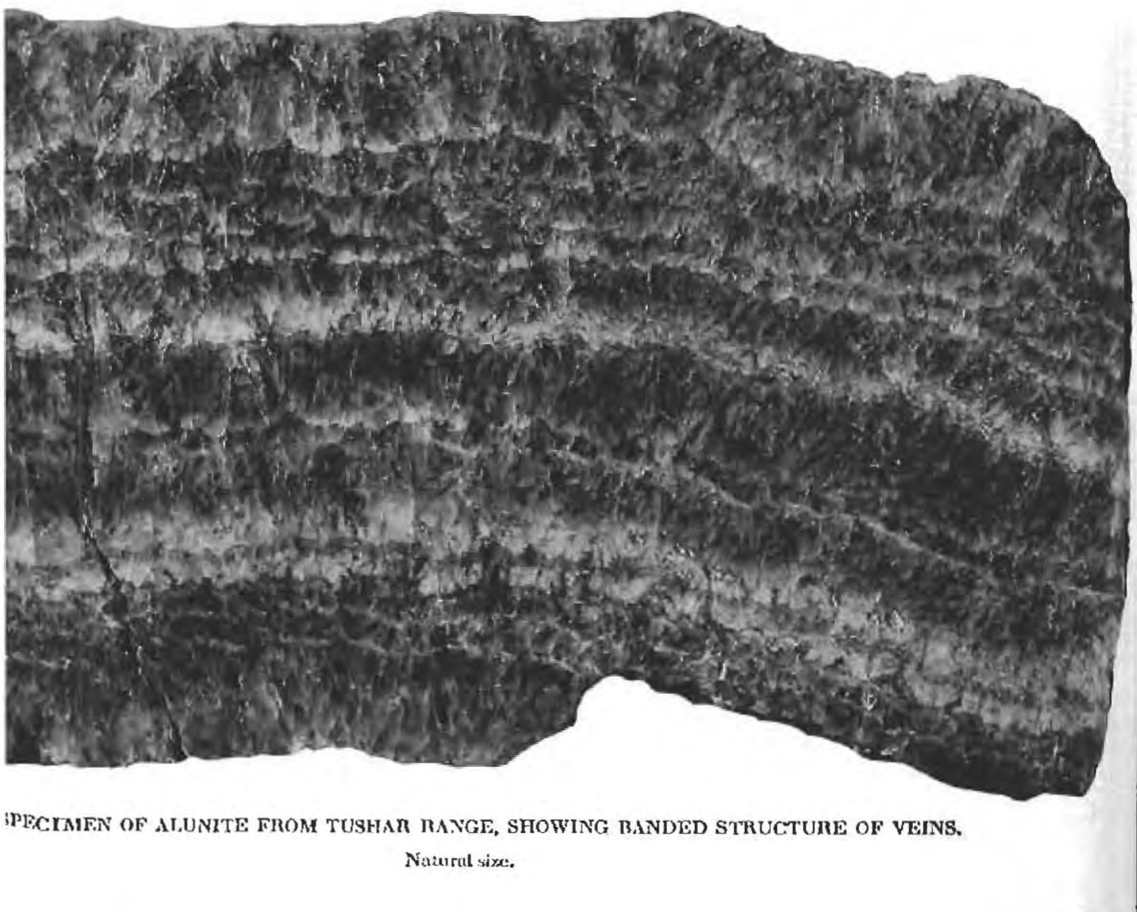
B. PHOTOMICROGRAPH OF SPECIMEN OF HIGHLY ALTERED WALL ROCK ADJACENT TO VEINS FROM GOLD SPRINGS DISTRICT.

[illegible] light areas quartz. Enlarged 30 diameters.



PHOTOMICROGRAPH OF SPECIMEN OF ALUNITE FROM TUSHAR RANGE, SHOWING PLUMOSE CHARACTER OF CRYSTALS.

Enlarged 25 diameters.



SPECIMEN OF ALUNITE FROM TUSHAR RANGE, SHOWING BANDED STRUCTURE OF VEINS.

Natural size.

extent there has been sericitization and, where alteration is slight, chloritization of the dark silicates. In the Tushar Range the prevailing metasomatic alteration has been of the latter character.

No chemical analyses are available that show the quantitative changes that took place in the alteration, but there was evidently removal of soda, lime, and magnesia, and notable additions of potassium. The mineralogic alteration was much greater than the chemical.

Gold and silver deposits of this type in Utah have not yielded large returns. The Annie Laurie mine was an important producer for several years, and numerous other mines have produced a little ore, but developments so far do not give reason for expecting large production. However, the districts in which the deposits occur have not been extensively prospected and valuable deposits may yet be found. Probably also improvements in metallurgy will make it possible to treat some partly developed ores of too low grade to be profitably handled at present. Similar deposits are abundant in other Western States and have yielded large amounts of gold and silver. Like the Utah deposits they differ greatly in their relative content of gold and silver. They include the Comstock, Tonopah, Rawhide, and Bullfrog districts in Nevada [1] and many others.

ALUNITE VEINS.

Veins composed essentially of the mineral alunite and having value for their potassium and possibly for their aluminum content have been worked in the Tushar Range.

The deposits are distinctly banded or crustified (see Pl. XX) and have apparently been formed for the most part as a filling of open fissures. The vein material, which is essentially pure alunite, varies in texture from rather coarsely crystalline to fine and porcelain-like, and in many places has a slightly schistose structure, probably due to movements along the vein.

Some of the wall rock has been highly altered for scores of feet from the main vein, usually to a rock composed essentially of quartz, alunite, and pyrite. (See Pl. XXI.) The alunite has replaced feldspar and other aluminous minerals, and the silica, freed by the breaking up of the silicates, has crystallized as fine-grained quartz. The iron of the dark silicates, in large part at least, has combined with sulphur to form pyrite.

No chemical analyses are available to show the quantitative changes, but mineralogic study discloses that essentially all the soda, calcium, and magnesium were removed and that large amounts of sulphur and water were added. The changes in silica, alumina, and potassium are not so readily determined. The potassium in the original rock seems sufficient to form the alunite in the altered rock and some of it may have been removed. In the absence of chemical analyses it is uncertain to what extent the alumina and the silica have been changed. (See also p. 184.)

RELATIONS OF DIFFERENT TYPES OF VEINS TO ONE ANOTHER AND TO OTHER TYPES.

The close genetic relation between the gold-silver veins and those containing important amounts of base metals (see p. 179) is perhaps best shown in the Tushar Range, where there is practically every graduation from veins containing but small amounts of the base metals to those in which tetrahedrite is rather plentiful, and from these in turn to veins containing abundant tetrahedrite, sphalerite, and galena. The same conditions exist, in lesser degree, in the zone extending from the State Line district southward through Gold Springs and Modena to the Escalante mine. In the San Francisco district the gold-silver veins are not represented, but the lead-silver-zinc-copper veins show so many similarities to those in the Tushar Range that there can be little doubt that they belong in the same type. It seems reasonable to conclude then that the precious metal and base metal veins are members of a continuous series.

The alunite veins, so far as known, are present only in the Tushar Range, where their relationship to the other veins of the district is indicated by their presence in the main mineralized zone, by their general conformity in strike with the metal-bearing veins, and by their composition. The metal-bearing veins are notably rich in potash and aluminum and in this respect resemble the alunite veins. The notable difference of the two lies in the absence, so far as known, of the common metals of the district from the alunite veins and in the presence in them of abundant sulphate, which appears in the other veins in

[1] Lindgren, Waldemar, Mineral deposits, pp. 475-512, 1913.

relatively small amount as barium sulphate (barite).

Alunite deposits have been found only in the Tushar Range, where erosion since the deposits were formed has been relatively slight, and are absent from districts like the San Francisco, where erosion has been relatively great, deeply exposing the intrusive bodies beneath the lavas. It seems not improbable that alunite formed only near the surface and has been preserved only where erosion has been exceptionally slight. This interpretation seems to agree with occurrences in the San Juan region of Colorado.[1]

In the Tushar Range the deposits in the volcanic rocks may be attributed to a common origin with deposits in the sedimentary rocks (p. 552), and those in the sedimentary rocks in turn show a genetic relation to those in the intrusive rocks. The same holds true in the San Francisco district. In the Gold Springs–State Line district no intrusive or sedimentary rocks have been recognized, but it seems reasonable to attribute the deposits in the volcanic rocks to a similar origin.

It has already been pointed out that the deposits in the intrusive and sedimentary rocks were derived (see p. 177) from materials differentiated from crystallizing igneous material. In the volcanic rocks the differentiates have risen along well-defined fissures from deep-seated sources, probably from bodies of intrusive quartz monzonite, which in the Tushar and San Francisco ranges have been partly exposed by erosion.

It is evident that a notable change took place in the character of the solutions during the formation of the deposits in the volcanic rocks and during the passing of the solutions from their deep-seated source toward the surface.

The earliest solutions deposited abundant carbonates and some sulphate (barite). They were followed by solutions that deposited abundant quartz and feldspar and some metallic minerals that replaced the earlier carbonates. The alunite veins were apparently deposited near the surface, and it is not certain whether they were formed later than the quartz-adularia veins, after the solutions had further changed in character, or were deposited from solutions which had become relatively rich in sulphates by the removal of the carbonates, silicates, and sulphides or from solutions containing abundant hydrogen sulphide that had been oxidized near the surface by admixture with descending solutions.

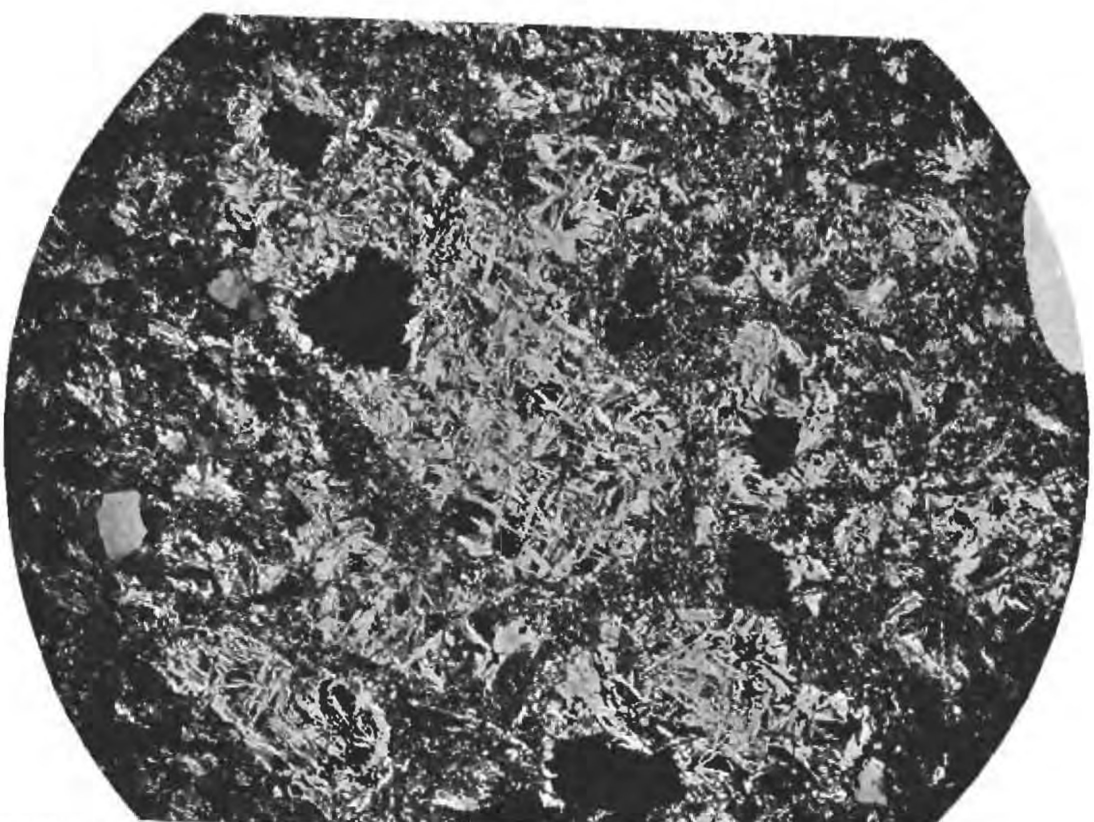
The origin of the potassium and aluminum of the alunite is also uncertain. The gold-silver veins are rich in both, and in some places, especially in the Gold Springs–State Line district, they have been added to the wall rock, which would suggest that these constituents were derived from deep-seated sources. On the other hand, some of the deeper-seated deposits in the lavas, as in the Horn Silver mine, and some of the deposits in the associated intrusive rocks, as in the Antelope Mountains northeast of Marysvale, show a pronounced leaching of aluminum and potassium from adjacent rock, together with most of the other elements with the exception of silica. This suggests that potassium and aluminum, together with other elements, may have been leached from the deeper zone and redeposited near the surface where conditions of solution were less favorable. The alteration of the wall rocks indicates that, with the exception of silica, aluminum and potassium were the last elements to be removed in the zone of leaching, and it seems reasonable to suppose that they would be among the earliest to be deposited (following quartz). It might be supposed then that much of the vein material was leached from the rocks adjacent to the veins at lower horizons and redeposited as it rose toward the surface, the quartz or the quartz and feldspar being deposited before the alunite and the more soluble materials deposited nearer the surface, where they have since been eroded, or carried out on the surface in thermal springs.

That sulphates become relatively abundant in the later stages of ore deposition is indicated at numerous localities, especially in the Cactus deposit, where anhydrite was abundantly deposited during the later stages of deposition. Barite is abundant in the Tintic deposits, which were formed under relatively shallow conditions and from which small amounts of alunite are reported. Barite is also an abundant gangue in the Horn Silver deposit, and occurs in deposits in the volcanic rocks in the

[1] Cross, Whitman, Geology of Silver Cliff and Rosita Hills, Colo.: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 2, pp. 263–403, 1906. Cross, Whitman, and Spencer, A. C., Geology of Rico Mountains, Colo.: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 92–94, 1900. Larsen, E. S., Alunite in the San Cristobal quadrangle, Colo.: U. S. Geol. Survey Bull. 530, pp. 179–183, 1913.

A. PHOTOMICROGRAPH OF A SPECIMEN OF ROCK FROM SHEEP ROCK, ON THE WEST SIDE OF TUSHAR RANGE, SHOWING BANDING OF ALUNITE AND QUARTZ.

Enlarged 30 diameters.



B. PHOTOMICROGRAPH OF SPECIMEN SHOWING WALL ROCK OF ALUNITE VEIN ALTERED TO ALUNITE, MARYSVALE DISTRICT.

Dark areas, pyrite; lath-shaped crystals, alunite; groundmass, intergrowth of alunite and quartz. Enlarged 30 diameters.

Tushar Range, where, however, it has been locally replaced by quartz and adularia.

The solutions that formed the ore in the Horn Silver deposit removed potassium, aluminum, and other constituents from the wall rock (p. 519). As the solutions passed upward they doubtless contained the sulphate radicle together with potassium, aluminum, and water—all the constituents of alunite—and it seems entirely possible that at some higher horizon, now removed, alunite deposits similar to those of the Tushar Range may have been formed.

A mineral occurrence of especial interest in this connection is that of hinsdalite, similar in character to alunite ($2PbO.3Al_2O_3.2SO_3.P_2O_5.6H_2O$), which occurs in the Golden Fleece mine,[1] near Lake City, Hinsdale County, Colo. It occurs as an original vein mineral with quartz, barite, pyrite, galena, tetrahedrite, and rhodochrosite in a vein cutting a series of volcanic rocks. Its general occurrence is in many respects similar to that of alunite in the deposits in the volcanic rocks of Utah. Larsen[2] has suggested a possible relation between the hinsdalite in the Golden Fleece mine and the alunite of the neighboring deposits, and considers it as most readily explained as formed by "deep-seated hot sulphuric acid solutions without the aid of surface agents." For further discussion see page 84.

COMPARISON OF DIFFERENT TYPES OF DEPOSITS ASSOCIATED WITH IGNEOUS ROCKS.

GENERAL FEATURES.

If, as seems probable, most of the ore deposits of western Utah associated with igneous rocks were deposited from solutions migrating upward and outward from differentiating magmatic material into zones of successively lower temperature and pressure, then even those in the different types of rock should show certain similarities corresponding to similar conditions of temperature and pressure.

Such similarities might be expected, for instance, between deposits in the sedimentary rocks and those in the extrusive rocks. The zone of highest temperature and pressure in the sedimentary rocks contains contact deposits which have copper and iron as their chief valuable metal constituents. Nowhere in the State, however, are corresponding deposits in the extrusive rocks found.

Failure to find such deposits may be attributed to one of two principal causes or a combination of the two. First, the contact deposits in the sedimentary rock were formed where the solutions passed into a chemical environment very different from the one they had been traversing and the deposits were due in large part to chemical reactions. In passing from an intrusive to an extrusive rock, on the other hand, the chemical conditions are not greatly changed and important reactions are not induced. Second, most intrusions into sedimentary rocks occurred at great depth and consequently under conditions of temperature and pressure favorable to the formation of contact deposits. Intrusions into extrusive rocks, on the other hand, occurred relatively near the surface under correspondingly unfavorable conditions for the formation of deep-seated deposits. Either individually or jointly these causes would tend to prevent the formation of deposits in extrusive rocks corresponding to the contact deposits in the sedimentary rocks.

Deposits formed in the sedimentary rocks under conditions of moderate and relatively low temperature and pressure (the replacement fissure deposits) have closely analogous types in the deposits in the extrusive rocks. The base-metal deposits in the extrusive rocks in the Horn Silver and Beaver Carbonate mines of the San Francisco district and in less important mines in the Tushar Range resemble the replacement veins in the sedimentary rocks of the Tintic, Park City, Bingham, and other districts. The similarity of the deposits of the Horn Silver mine to those of the Tintic district is especially striking, the rock in both places having been largely replaced by cherty quartz and the gangue minerals in both being fine-grained quartz and barite. Again, the gold-silver veins in the extrusive rocks of the Tushar Range and Gold Springs-State Line area resemble certain deposits in the sedimentary rocks that have their greatest value in the precious metals but that contain also copper, lead, zinc, arsenic, antimony, and locally quicksilver. Such deposits are present in the Tintic district and in the Tushar Range (in the Deertrail mine) but have been most extensively

[1] Larsen, E. S., jr., and Schaller, W. T., Hinsdalite, a new mineral Am. Jour. Sci., vol. 32, pp. 251-255, 1911. Irving, J. D., and Bancroft, Howland, Geology and ore deposits near Lake City, Colo.: U. S. Geol. Survey Bull. 478, p. 54, 1911.

[2] Larsen, E. S., jr., Alunite in the San Cristobal quadrangle, Colo.: U. S. Geol. Survey Bull. 530, p. 182, 1913.

mined in the Lion Hill section of the Ophir district and in the Mercur district. Both types of rock contain deposits in which gold predominates and other deposits in which silver predominates. In the extrusive rocks both gold deposits and silver deposits occur in the different veins of the Tushar Range and Gold Springs–State Line districts, and in the sedimentary rocks gold deposits occur in the Mercur district and silver deposits in the neighboring Lion Hill district.

In the Tushar Range (see p. 552) there appears to be a progressive change in the character of the deposits as the distance from their source increases or as more deep-seated give place to less deep-seated conditions; and in general the relative amounts of the precious metals increase as the distance from the source increases or as less deep-seated conditions are attained. A similar condition exists in the deposits in the sedimentary rock in the Oquirrh Range in passing outward from the main intrusive body in the Bingham district through the lead-zinc-copper-silver-gold deposits of the Stockton and Ophir districts to the essentially silver deposits of the Lion Hill and the gold and quicksilver deposits of the Mercur and adjacent districts. It may be noted that arsenic and antimony are more abundant in deposits formed at relatively shallow depth.

In the Tintic district, however, Lindgren notes that gold is most abundant near the intrusive rocks. Silver increases with increased distance from the intrusive bodies to a maximum beyond which there is a decrease, the lead and zinc in the extreme outer zone being accompanied by relatively little silver.

No deposits that bear a close analogy to the alunite veins in the extrusive rocks have been recognized in the sedimentary rocks. However, some of the deposits in the sedimentary rocks that are believed to have formed at relatively shallow depth are, like the deposits in the extrusive rocks, rich in potassium and aluminum. This is notably true of the Deertrail deposit, of the Mercur deposits, and of some of the deposits in the Ophir district.

SIGNIFICANCE OF PRIMARY SULPHATE MINERALS IN THE GENESIS OF ORE DEPOSITS.

FORMATION OF SULPHATE MINERALS.

In studying ore deposits the writer has several times been confronted with the problem of accounting for the formation of sulphate minerals that are apparently primary. These minerals occur at places where no evidence can be found of their formation by surface oxidation. Either they were formed directly by igneous emanations or, if they were formed by surface agencies, those agencies must have affected the deposits of other associated minerals that would ordinarily be regarded as of hypogene origin. An attempt will be made to analyze this problem by starting with the belief, based on deductions from field observations, that the sulphates in certain deposits have been formed directly by igneous emanations. To avoid complications the occurrence of the minerals in deposits that are not generally regarded as associated with igneous rock is discussed only incidentally. It is recognized that nearly all the sulphates that occur as apparently primary minerals in ore deposits associated with igneous rocks have also been formed in places where they are not associated with igneous rocks. It is likewise recognized that in the formations of at least some of the primary sulphates in ore deposits that are associated with igneous rocks surface agencies may have played a part. The general conclusion reached is that some of the metals that at high temperature are combined with oxygen give up oxygen as the temperature is reduced, and both the metals and the oxygen tend to combine with sulphur, producing sulphides of the metals and oxides of sulphur. At suitable temperatures the sulphites and sulphates are doubtless formed and the less soluble sulphates are deposited. Moreover, it is believed that certain conditions lead to the formation of free sulphuric acid, which, on reaction with potassium-aluminum rocks, forms alunite.

SULPHATE MINERALS.

Brief summaries of the occurrence of the principal primary sulphate minerals in igneous rocks or of the sulphate minerals that are apparently primary in veins which are believed to be associated with igneous rocks are given below. No attempt is made to include in this summary occurrence of these minerals in other relations, or to give a complete list of localities.

Haüynite and noselite.—Haüynite $[(Na_2Ca)_2(NaSO_4Al)Al_2(SO_4)_3]$ and noselite $[Na_4(NaSO_4Al)Al_2(SiO_4)_3]$ are primary minerals in certain rather uncommon types of eruptive rocks such as those of the Cripple Creek volcano. It is

noteworthy that these minerals are characteristic components of volcanic rocks, whereas the closely related chloride minerals are components of plutonic or deep-seated rocks. In Utah they are known in small dikes, as those in the La Sal mountain laccoliths.

Barite.—Barite ($BaSO_4$) is perhaps the most common primary sulphate vein mineral. It occurs usually if not invariably in deposits formed at moderate and low temperature[1] or among later minerals formed in deposits that contain minerals deposited at high temperature. Barite also occurs where it is not known to be related to igneous rocks.

It is difficult to determine even approximately the temperature at which any mineral deposit was formed, but Lindgren[2] has grouped the minerals in such deposits in three classes—those formed at low temperature (200° C. or less, perhaps much less), at moderate temperatures (175° to 300° C.), and at high temperatures (300° to 575° C.). Contact deposits may have been formed at much higher temperatures, such as those of magmas, which range from 800° to 1,400° C.

Anhydrite.—Anhydrite ($CaSO_4$) has only recently been recognized as a primary vein mineral, and its associations indicate deposition at moderate temperature. Anhydrite has the unusual property of decreasing in solubility with increase of temperature, being but slightly soluble at 200° C.[3]

It might be supposed that anhydrite would form most abundantly in deposits that replace limestone, but the recorded occurrences do not justify this supposition. Probably the abundant carbon dioxide that must necessarily be present in solutions that are replacing limestone inhibits the precipitation of calcium sulphate.

Lindgren[4] first observed anhydrite as a vein-forming mineral in the Cactus mine, Utah, where it occurs in a vein in monzonite associated with tourmaline, hematite, pyrite, chalcopyrite, barite, and siderite. Anhydrite, barite, and siderite were among the latest minerals to form. Lindgren gave the following suggestion as to the origin of the anhydrite:

It is suggested as a possibility that during the later part of mineralization the anhydrite was precipitated by a reaction between ascending solutions of sodium sulphate and descending solutions containing calcium carbonate.

The writer[5] accepted this interpretation, but with reservations and doubts that are among the motives which led to the preparation of this discussion.

Anhydrite occurs in the Bully Hill district, Calif., in lodes in alaskite porphyry and is associated with pyrite, chalcopyrite, sphalerite, and barite. Graton[6] apparently regards it as having been deposited directly from ascending solutions.

Boyle[7] also regards the gypsum and anhydrite of the Bully Hill district as of deep-seated origin, supposing that the calcium was derived from the limestone through which the solutions passed.

Anhydrite is reported from the Cobre district, Santiago, Cuba. The deposits are in andesite tuff cut by dikes of andesite. The associated minerals are pyrite, chalcopyrite, and quartz.[8]

Geÿer[9] describes anhydrite in deposits in Sweden associated with tremolite, galena, chalcopyrite, and pyrite.

Hewett[10] and Miller and Singewald[11] have described the remarkable deposits of the Minasragra vanadium mine of Peru. Hewett is quoted by Miller and Singewald as follows:

The central lens of patronite (a greenish-black mineral that is a sulphide of vanadium), coke (a dull-black vesicular hydrocarbon), and quisqueite (a black lustrous hydrocarbon) which attains a maximum thickness of nearly 30 feet, is entirely inclosed in a zone of material that is locally called veta madre, which is about 40 feet thick on both walls of the smaller lines and extends beyond its ends. Veta madre is a mixture of earthy material, disseminated sulphide of vanadium, and anhydrite, which is largely altered to gypsum on the level of tunnel No. 2, 120 feet below the surface. It represents shale that has been more or less saturated by sulphide of vanadium and replaced by anhydrite. * * * It appears that after the intrusion of the dikes of igneous rocks, the "dike"-like lens

[1] Emmons, W. H., A genetic classification of minerals: Econ. Geology, vol. 3, p. 618, 1908.

[2] Lindgren, Waldemar, Mineral deposits: McGraw-Hill Publishing Co., New York, 1913.

[3] Melcher, A. C., Am. Chem. Soc. Jour., vol. 32, pp. 50-66, 1910.

[4] Lindgren, Waldemar, New occurrence of willemite and anhydrite: Science, new ser., vol. 28, p. 933, 1908.

[5] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80 p. 124, 1913.

[6] Graton, L. C., The occurrence of copper in Shasta County, Calif. U. S. Geol. Survey Bull. 430, p. 100, 1910.

[7] Boyle, A. C., jr., Geology and ore deposits of the Bully Hill mining district, Calif.: Am. Inst. Min. Eng. Trans., vol. 48, p. 111, 1915.

[8] Emerson, E. H., Geologia de las minas: Bol. de Minas, Cuba, No. 4, pp. 47-52, 1918.

[9] Geÿer, Per, Falutraktens berggrund ock malmfyndigheter: Geol. Survey Sweden Årsbok, 1916, p. 156.

[10] Hewett, D. F., Am. Inst. Min. Eng. Trans., vol. 40, pp. 274-299, 1909.

[11] Miller, B. L., and Singewald, J. T., The mineral deposits of South America, pp. 487-491, New York, McGraw-Hill Book Co., 1919.

of patronite, coke, and quisqueite entered a crushed zone in red shale. At the same time the shale walls were partially replaced by anhydrite and sulphide of vanadium.

Bastin [1] has described primary anhydrite and gypsum in the Braden copper deposits of Chile. The rocks and ores of the district record a complicated series of igneous activities, including extrusions and intrusions and three distinct periods of mineralization. The minerals of the first period were tourmaline and relatively small amounts of pyrite and chalcopyrite. The minerals of the second period were mainly quartz, pyrite, and chalcopyrite and small amounts of black tourmaline and a little biotite. The metallic minerals of the third period include pyrite, chalcopyite, bornite, galena, sphalerite, molybdenite, tennantite, enargite, and hübnerite, and the gangue minerals siderite, rhodochrosite, calcite, anhydrite, gypsum, and barite. The mineralization of the third period is thought by Bastin to have taken place at a lower temperature than that of the earlier periods and was characterized by solution of tourmaline as contrasted with deposition of that mineral in the first two periods.

Anhydrite is also present in the copper deposits of Cuka-Dulkan at Bor, Serbia.[2] It is regarded by Lazarevic, however, as secondary.

Anhydrite occurs most abundantly where it is not associated with either igneous rocks or veins.

Gypsum.—Gypsum is a common mineral in ore deposits but has doutless usually been formed by the alteration of anhydrite or by reaction between solutions of sulphuric acids (produced by the oxidation of sulphides) and calcium-bearing minerals. As already noted, Bastin considers gypsum in the Braden mine as primary.

Adolph Knopf has kindly furnished the following note on the occurrence of gypsum at the Utica mine, Calif.:

The ore on the 2,100-foot level of the Utica mine, on the Mother Lode at Angels, Calif.—a low-grade ore averaging $2 in gold—consists of quartz and subordinate dolomite, gypsum, and, as shown under the microscope, albite. The only sulphide present is some extremely fine grained galena disseminated in small patches. The vein, which is vertical, is inclosed in amphibolite schist, and the vein and country rock are so impervious and dry that the mine workings are dusty, although the mine above the 900-foot level makes large quantities of water. The gypsum is intimately intergrown with the quartz, and this fact, together with its occurrence so far below the zone of oxidation and the obvious imperviousness of the vein to descending waters, suggests that the gypsum is a primary (hypogene) constituent of the ore. Under the microscope the gypsum is seen to be intergrown with quartz in patterns somewhat like micrographic intergrowths, and this feature possibly corroborates the evidence of its primary origin.

Celestite.—Celestite, like barite and anhydrite, occurs in deposits formed at intermediate to low temperature and also at many places where it is not associated with igneous rocks.

Alunite.—Alunite has the chemical formula $K_2O.3Al_2O_3.4SO_3.6H_2O$, in which Na may replace K in varying proportions. Alunite is perhaps the most abundant and widely distributed sulphate mineral that is associated with altered volcanic rocks. It occurs also as a secondary (supergene) mineral in the oxidized zone of ore deposits. Its genesis has been variously interpreted by different geologists, doubtless because it has been formed in various ways. The occurrences of the mineral have been summarized by Ransome [3] and later by Butler and Gale.[4]

Perhaps the best-known deposit worked for alunite is that at Tolfa, Italy, where the alunite occurs in trachyte and is said to give place in depth to pyritic trachyte. Concerning the formation of the alunite De Launay says:[5]

Alunite is, in my opinion, a product of the decomposition of feldspar similar to kaolin, which is worked in the same region, and often from the same vein, and, like this kaolin, is bound to disappear in depth. The theory which was formerly held is somewhat different. It was thought that the sulphur vapors of solfataric kinds circulated in the fissures of trachyte and attacked directly in depth the feldspars of the latter, and a relation was supposed to exist between these different phenomena and the trachyte itself. I believe, on the contrary, that there are two entirely distinct phases in the phenomenon—first, a vein deposit, clearly delimited, of pyritic trachyte, corresponding perhaps to the veins of a trachyte particularly feldspathic and at the same time pyritic like the granulites of Berezowsk (Oural); second, penetration by superficial waters of the feldspathic rocks, producing, where pyrite fails, the ordi-

[1] Bastin, E. S., private report based on detailed study.

[2] Lazarevic, M., Enargit-covellin-lagerstätte von Cuka-Dulkan bei Bor in Ost-Serbien: Zeitschr. prakt. Geologie, vol. 20, p. 337, 1912.

[3] Ransome, F. L., The geology and ore deposits of Goldfield, Nev.: U. S. Geol. Survey Prof. Paper 66, pp. 180-185, 1909.

[4] Butler, B. S., and Gale, H. S., Alunite, a newly discovered deposit near Marysvale, Utah: U. S. Geol. Survey Bull. 511, 1912.

[5] Translation by Butler, B. S., and Gale, H. S., op. cit., p. 52, from De Launay, L., La métallogénie de l'Italie: Cong. géol. internat., 10th sess., Compt. rend., pt. 1, 1907.

nary forms of altered feldspars—that is to say, kaolin—but where, on the other hand, pyrite furnishes sulphuric acid, crystalline alunite.

Lindgren [5] and others have described the occurrence of alunite formed by the action of solutions that contained sulphuric acid, which were derived from oxidizing sulphides on potassium-aluminum silicates.

In the United States there are numerous deposits of alunite which are believed to have been formed and others that are perhaps now forming by the action of hot sulphurous waters on potassium-aluminum rocks. Large bodies of volcanic rock so altered are composed chiefly of quartz, alunite, and pyrite. The calcium, magnesium, and sodium were largely removed from the original rock, but iron appears to have been converted to pyrite at the same time that alunite was formed. In discussing the origin of the gold deposits at Goldfield, Nev., Ransome [2] states

that the ore constituents were brought up in hot solutions charged with hydrogen sulphide, a little carbon dioxide, and probably also with some alkali sulphides; that the hydrogen sulphide was oxidized at and near the surface to sulphuric acid, which percolated down through the warm rocks to mingle with the uprising currents carrying sulphydric acid.

For the deposits near Marysvale, Utah, which occur as veins in effusive rocks and have been developed for the alunite, Butler and Gale say: [3]

The evidence in the Marysvale district, however, indicates that the materials constituting the veins were deposited by ascending solutions and that these solutions brought in the constituents of the alunite. At just what stage the sulphuric acid may have been formed can not now be positively stated, but it seems most natural to suppose that it was a part of the original solutions and that the potassium and aluminum were in part original in the solution and in part dissolved from the walls of the fissure at greater depth.

The veins in this district are nearly pure alunite, but the altered wall rock is mainly alunite, quartz, and pyrite. Concerning alunitized rocks at Rico Mountains, Colo., Cross [4] writes:

The alteration of the porphyry of Calico Peak into a rock consisting largely of alunite, a hydrous sulphate of alumina and the alkalies, * * * can be explained only as the result of the attack of sulphurous agents, and from the circumstances of occurrence there can be no doubt that the action is to be attributed to solfataric emanations of the Rico eruptive center in the period of waning igneous activity.

Larsen [1] has described several areas of alunitized rock in Colorado. The altered rocks consist essentially of quartz, alunite, and pyrite, one analysis giving quartz, 69 per cent; alunite, 29 per cent; and pyrite, 2 per cent. Concerning the genesis of these deposits Larsen writes:

The evidence suggests hot ascending solutions as the cause of the alunitization. The field relations point strongly to deep-seated hot sulphuric acid solutions without the aid of surface agents. However, in view of the fact that geologists do not generally admit the presence of such solutions, the evidence in the present case is not sufficient to justify the assumption of such a source for the alunitization in the San Cristobal quadrangle. The alternative source is the mingling of hot ascending solutions or gases carrying H_2S and of surface oxidizing waters.

Clapp [6] regards the deposit of Kynquot Sound, British Columbia, as formed by "hot ascending solutions of volcanic origin and that at least these solutions causing alunitization carried free sulphuric acid."

A. L. Day and E. T. Allen have studied the hot springs of Mount Lassen, Calif., where alunite and pyrite are being deposited in the acid waters of the springs.[7]

Descriptions of occurrences of alunite could be multiplied but the above seem sufficient to give the general modes of occurrence.

Hinsdalite.—Hinsdalite ($2PbO.3Al_2O_3.2SO_3.P_2O_5.6H_2O$) from the Golden Fleece mine, near Lake City, Colo., has been described by Larsen [8] and by Irving and Bancroft.[9] It is a primary mineral in a vein in volcanic rocks associated with pyrite, tetrahedrite, galena, pyrargyrite, quartz, rhodochrosite, and barite. Barite is abundant also in neighboring deposits. The deposits are regarded by Irving and Bancroft as forming at shallow to moderate depth.

Creedite.—Larsen [10] describes creedite ($CaSO_4.2CaF_2.2Al(F,OH)_3.2H_2O$) as occurring with barite and fluorite in a vein in Tertiary lavas near Wagon Wheel Gap, Colo. Larsen does

[1] Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Ariz.: U. S. Geol. Survey Prof. Paper 43, pp. 119, 120, 1905.

[2] Ransome, F. L., op. cit., p. 193.

[3] Butler, B. S., and Gale, H. S., op. cit., p. 36.

[4] Cross, Whitman, and Spencer, A. C., Geology of the Rico Mountains, Colo.: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 92-94, 1900.

[5] Larsen, E. S., Alunite in the San Cristobal quadrangle, Colo.: U. S. Geol. Survey Bull. 530, pp. 179-183, 1913.

[6] Clapp, C. H., Alunite and pyrophyllite in Triassic and Jurassic volcanics at Kynquot Sound, British Columbia: Econ. Geology, vol. 10, pp. 70-88, 1915.

[7] Allen, E. T., personal communication.

[8] Larsen, E. S., and Schaller, W. T., Hinsdalite, a new mineral: Am. Jour. Sci., 4th ser., vol. 32, pp. 251-255, 1911.

[9] Irving, J. D., and Bancroft, Howland, Geology and ore deposits near Lake City, Colo.: U. S. Geol. Survey Bull. 478, pp. 54-55, 1911.

[10] Larsen, E. S., and Wells, R. C., Some minerals from the fluorite-barite vein near Wagon Wheel Gap, Colo.: Nat. Acad. Sci. Proc., vol. 2, pp. 362-364, 1916.

not state whether he regards it as a primary or secondary mineral in the vein.

Thaumasite.—The unusual mineral thaumasite ($3CaO.SiO_2.SO_3.CO_2.15H_2O$) occurs in veins which cut contact-altered limestone in the Old Hickory mine, Beaver County, Utah.[1] It is regarded as forming under conditions similiar to those favorable to the formation of zeolites. The best known localities of this mineral in the United States are at West Paterson and other places in New Jersey, where it occurs in trap associated with zeolites.

Wilkeite.—Wilkeite[2] ($3Ca_3(P_2O_4).3Ca_2SiO_4.3CaSO_4.CaCO_3.CaO$) occurs in contact-altered limestone associated with wollastonite and garnet near Riverside, Calif.

Scapolite.—Scapolites occur as products of contact metamorphism and as alteration products of igneous rocks. Some of the scapolites contain the sulphate molecule.[3]

Svanbergite.—Svanbergite is apparently a rather rare primary mineral in ore deposits.[4]

CHARACTER OF ORE SOLUTIONS AS INDICATED BY VOLCANIC EMANATIONS.

The data concerning the composition of volcanic emanations have been summarized by many writers. A rather complete outline with bibliography has been prepared by Clarke[5] who briefly summarizes the results as follows:

> That the volcanic gases appear in a certain regular order has been shown by the various researches upon their composition, and especially by the labors of Deville and Leblanc. What, now, in the light of all the evidence, is that order, and what do the chemical changes mean?
>
> First. The gases issue from an active crater at so high a temperature that they are practically dry. They contain superheated steam, hydrogen, carbon monoxide, methane, the vapor of metallic chlorides, and other substances of minor importance. Oxygen may be present in them, with some nitrogen, argon, sulphur vapor, and gaseous compounds of fluorine.
>
> Second. The hydrogen burns to form more water vapor, and the carbon gases oxidize to carbon dioxide. From the sulphur, sulphur dioxide is produced. The steam reacts upon a part of the metallic chlorides, generates hydrochloric acid, and so acid fumaroles make their appearance.
>
> Third. The acid gases of the second phase force their way through crevices in the lava and the adjacent rocks, and their acid contents are consumed in effecting various pneumatolytic reactions. The rocks are corroded, and where sulphides occur hydrogen sulphide is set free. If carbonate rocks are encountered, carbon dioxide is also liberated.
>
> Fourth. Only steam with some carbon dioxide remains, and even the latter compound soon disappears.
>
> This seems to be the general course of events, although it is modified in details by local peculiarities. All of the substances enumerated in the lists of gases and sublimates given in the earlier portions of this chapter may take part in the reactions, and they do not seriously affect the larger processes which have just been described. The order is essentially laid down by Deville and Leblanc, except that the early evolution of hydrogen and carbonic oxide is taken into account. The current of events may be disturbed, so to speak, by ripples and eddies—that is, by subsidiary and reversed reactions—but its main course seems to be clearly indicated.[6]

Harker[7] states:

> Different types of solfataric action might be distinguished, and these are in some degree characteristic of different kinds of lavas. But it is also to be remarked that different volatile constituents may figure prominently at a given volcanic center at different stages in decline of activity. This is in part a matter of direct observation; for it has frequently been remarked that only the hottest fumaroles emit hydrochloric and hydrofluoric acids, while sulphurous and hydrosulphuric acids are connected with lower temperatures of emission, and water and carbonic acid with the lowest temperatures. Some indications of a like sequence have already been noted in pneumatolysis under plutonic conditions.

The volcanic emanations contain carbon, hydrogen, sulphur, oxygen, nitrogen, and minor constituents such as chlorine, fluorine, and metals in varying proportions and combinations depending probably both on the original character and the temperature of the gases. Day and Shepherd[8] collected gases from Kilauea with great care to avoid contamination with air, and state that the absence of argon "affords a most desirable confirmation of our belief that the volcano gases were successfully collected before they had come in contact with atmospheric air at all and were

[1] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, p. 104, 1913.

[2] Eakle, A. S., and Rogers, A. F., Wilkeite, a new mineral of the apatite group, and okenite, its alteration product from southern California: Am. Jour. Sci., 4th ser. vol. 37, p. 262, 1914.

[3] Borgström, L. H., Die Skapolithlagerstätte von Laurinkari: Com. geol. Finland, Bull. 41, p. 23. 1913.

Brauns, R., Skapolithführende Auswürflinge aus dem Laacher Seigebiet: Neues Jahrb., Beilage Band 39, p. 119, 1914.

[4] Lacroix, A., Pyritiferous deposits at the contact of granite at Chezeuil, Saone-et-Loire, and its metamorphic rocks: Soc. franç. min. Bull. 41, pp. 14–21, 1918.

[5] Clarke, F. W., The data of geochemistry, 3d ed.: U. S. Geol. Survey Bull. 616 pp. 280–290, 1916.

[6] For a summary of our knowledge concerning the magmatic gases previous to the work of Brun and Chamberlin, see Lincoln, F. C., Econ. Geology, vol. 2, p. 258, 1907. Lincoln gives a good table of analyses and proposes a classification of the volcanic exhalations. For a theoretical discussion relative to "gas mineralizers" in magmas see Niggli, P., Zeitschr. anorg. Chemie, vol. 75, p. 161, 1912, and vol. 77, p. 321, 1912. Also Centralbl. Mineralogie, 1912, p. 321; and Geol. Rundschau, vol. 3, p. 472, 1912.

[7] Harker, Alfred, The natural history of igneous rocks, p. 307, Methuen & Co., London, 1909.

[8] Day, A. L., and Shepherd, E. S., Water and volcanic activity: Geol. Soc. America Bull., vol. 24, p. 588, 1913.

therefore entirely uncontaminated either by reaction or admixture with it." These gases were analyzed with the following results:

Composition of gases from Halemaumau (Kilauea), Hawaii, May, 1912.

[Percentages by volume.]

	Tube 1.	Tube 2.	Tube 8.	Tube 10.	Tube 17.
CO_2	23.8	58.0	62.3	59.2	73.9
CO	5.6	3.9	3.5	4.6	4.0
H_2	7.2	6.7	7.5	7.0	10.2
N_2	63.3	29.8	13.8	29.2	11.8
SO_2	None.	1.5	12.8	None.	None.
Rare gases	None.	None.	None	None.	None.
Hydrocarbons	None.	None.	None.	None.	None.

These gases contained abundant water and before cooling more sulphur dioxide than is shown in the analysis. The authors say:

> The SO_2, for example, has gone over in part or altogether to SO_3 and gone into solution, and only two of the five tubes analyzed now show SO_2 as such. Moreover, the resulting acid solutions may have reacted to a limited extent on the glass tube and accordingly be responsible for all or a part of the alkalies, lime, and alumina shown in the analyses of water.

The writer understands that the authors cited do not suppose that any sulphuric acid was formed from original constituents on the cooling of the gases.

The analyses of the materials contained in the water are given in the following table:

Analyses of material contained in the water collected in the tubes of gases from Halemaumau, Hawaii.

	Tube 1.	Tube 2.
	Gram.	*Gram.*
Na_2O	a 0.0214	a 0.031
K_2O	a .0102	a .011
CaO	a .0120	a .14
Fe_2O_3, Al_2O_3	a .080	a .010
Cl	.220	.206
F	.165	.492
NH_3	.0018	None.
TiO_2	.0057	None.
Total S as SO_3	.480	.308

a The major portion of these may have come from the glass or from Pele's hair.

The analyses recorded in the literature indicate that sulphur is present in different volcanic emanations as H_2S, SO_2, SO_3, and as sulphur vapor, and many of the analyses show free oxygen.

CONDITIONS OF FORMATION OF SULPHUR TRIOXIDE.

It is obvious that the first step in the deposition of the sulphate minerals is the formation of the sulphate radicle, and the conditions under which this radicle forms are therefore of interest. The commercial importance of sulphuric acid has led to careful investigation of the modes of formation of sulphur trioxide. Much information on this subject has been brought together by Lunge.[1]

Sulphuric acid can be formed in many ways, but one way in which it may be formed in igneous emanations is that known as the contact process. This process consists essentially in bringing about the combination of sulphur dioxide and oxygen by the aid of a catalyzer. Knietsch, as stated by Lunge,[2] has shown the reaction at different temperatures at atmospheric pressure. Lunge[3] says:

> The most important result of Knietsch's experiments was that a line of stable equilibria exists which divides the range of temperature into two parts [with the catalyzers used]. The range below 200° and above 900° or 1,000° may be called devoid of reaction in a technical sense; between 200° and 450° the reaction of formation prevails; above 450° the dissociation of SO_3 comes into play very rapidly.

It is apparent that the range of temperature in which sulphur trioxide forms at all rapidly and is stable under atmospheric pressure and in a system containing only sulphur and oxygen is not large.

In the manufacture of sulphuric acid the catalyzer commonly employed is platinum, but ferric oxide and many other substances act as catalyzers, so that many catalyzers may be present in mineral veins.

Another method of producing sulphuric acid, which is employed at the plant of the New Cornelia Copper Co. at Ajo, Ariz., should be mentioned here. In the treatment of copper ores the copper is leached by sulphuric acid and electrolytically precipitated. For successful precipitation it is necessary to keep the ferric iron of the solutions low. When the solutions become polluted with ferric sulphate, that substance is reduced to ferrous sulphate by spraying the solution through a chamber containing sulphur dioxide.[4]

The gas is cooled from 600° to 150° F. in passing through the chamber. The ferric iron in the solution is practically all reduced, according to the following reaction:[5]

$$Fe_2(SO_4)_3 + SO_2 + 2H_2O = 2\ FeSO_4 + 2H_2SO_4$$

[1] Lunge, George, The manufacture of sulphuric acid and alkali, 3 vols., New York, D. Van Nostrand Co., 1913.

[2] Lunge, George, op. cit., p. 1307.

[3] Idem, p. 1311.

[4] Tablemann, H. A., and Potter, J. A., First year of leaching by the New Cornelia Copper Co.: Am. Inst. Min. Eng. Bull. 146, p. 475, 1919.

[5] Idem, p. 478.

FORMATION OF SULPHURIC ACID IN NATURE.

The possible conditions under which sulphuric acid is formed in nature have been considered in detail by Ransome.[1] In discussing the origin of the ore deposits of Goldfield, Nev., Ransome considers three hypotheses—first, "the direct volcanic hypothesis," which postulates that the solutions come from deep-seated sources charged with sulphuric acid, a hypothesis supported by the presence of the sulphate-bearing minerals haüynite and noselite as original constituents of volcanic rocks and the presence of barite and celestite in mineral deposits that are generally believed to have been formed independently of surface agencies; second, "the hypothesis of the derivation of sulphuric acid from the oxidation of pyrite," a process so well known as to require no discussion; third, "the hypothesis of simultaneous solfatarism and oxidation," which postulates the rising of solutions containing hydrogen sulphide to or nearly to the surface, their oxidation to sulphuric acid by atmospheric oxygen, and the descent of the acid solutions thus formed into the veins again, where they react with the ascending solutions and cause the precipitation of metals, sulphides, etc.

FORMATION OF PRIMARY SULPHATE MINERALS.

In considering the formation of the primary sulphate minerals, it must of course be recognized that sulphates, either as minerals or in solution, are prevalent at the surface and that, if waters from the surface have had a large part in the formation of a mineral deposit, the insoluble sulphates would most naturally be formed. On the other hand, sulphates are often found where there is good reason to believe that surface waters were not involved in their formation, and we may inquire whether sulphates can form without the aid of surface agencies. First let us see what consequences follow the assumption that free oxygen is present in a given magmatic emanation, even though many investigators regard the presence of free oxygen in a magma as improbable. With such an emanation the formation of sulphur trioxide would not only be possible but under certain conditions would be inevitable. For instance, a gas that contained only sulphur or sulphur dioxide and free oxygen at 1,000° or higher temperatures would, on cooling, pass through the interval favorable to the formation of sulphur trioxide, and that compound would form. At the higher temperatures, at which sulphur trioxide is unstable, it would be in low concentration, and the formation and precipitation of abundant sulphates would not be expected, but when temperatures favorable to formation and stability were reached a high concentration might result and there would be a proportionate tendency to the formation of sulphates. It is natural to suppose that barium present in the form of the more soluble compounds would be the first substance to be precipitated as sulphate on account of the very slight solubility of barite in ore solutions, as indicated by its common occurrence. The same reasoning applies to some extent to the formation of anhydrite ($CaSO_4$) at high temperature and probably also to the formation of celestite. Barite is by far the most insoluble of the sulphates in pure water, and apparently also in mineralizing solutions, and, if it were not for this mineral, there would be little trace of sulphates as primary minerals except where near-surface conditions are reached. Such a development of sulphate would seem to be a more natural method for the formation of anhydrite, for example, than that suggested for the deposits of the Cactus mine, Utah, which did not account for the formation of the sulphate radicle. If the sulphate radicle actually forms in the cooling solution, it is easy to postulate a moderate supply of calcium from the alteration of the monzonite walls of the fissure, from which it is known that much calcium has been removed. It is possible that under favorable conditions the sulphate radicle may form to an extent that would result in a solution containing sulphuric acid, which in rocks high in alkali and aluminum would at favorable temperature give the conditions for the formation of alunite. As Ransome has pointed out, it is notable that solutions which form alunite apparently are not good carriers of metal. The Goldfield deposits are a distinct exception in their association with metallic sulphides, although cinnabar is associated with

[1] Ransome, F. L., The geology and ore deposits of Goldfield, Nev.: U. S. Geol. Survey Prof. Paper 66, pp. 189-195, 1909.

alunite in deposits east of Beatty, Nev., which have been described by Knopf.[1] The cinnabar occurs in silicified and alunitized rhyolite. In the great alunitized areas there does not appear to have been extensive removal of iron, much of which, whether originally present as oxide or in silicates, seems to have been altered to pyrite and remained. Morever, the alunite in the vein is remarkably free from other minerals. When sulphur trioxide had developed in the cooling solution to the extent of yielding sulphuric acid the solution probably ceased to be a carrier of most of the metals,[2] and the formation of sulphur trioxide may possibly be a factor in the precipitation of the metals.

The behavior of smelter gases gives some indication of the temperature at which certain sulphates will form abundantly under given conditions. Fulton[3] says:

The smoke stream also carries water vapor, the origin of which is the moisture in the ore charges fed to the furnaces. As long as the smoke stream has a temperature above 440° C., no combination of sulphur trioxide with water vapor to form sulphuric acid is possible, but as the temperature falls in the flues as the stack is approached, sulphuric acid vapor forms by the combination of water vapor and sulphur trioxide vapor, until at about 350° C. one-half of the sulphur trioxide present in the smoke stream is in the form of sulphuric acid vapor. At ordinary atmospheric pressure (760 millimeters) sulphuric acid, or rather a mixture of 98.54 per cent of sulphuric acid and 1.46 per cent of water, has a boiling point of 338° C. From this it follows that above 338° C. all sulphuric acid present must be in a vapor form or dissociated, but that below this temperature it may be present in the smoke stream in the liquid form as a fine mist or small liquid particles. * * * When the ore charge smelted or roasted contains a considerable precentage of volatile metals, such as lead, zinc, and cadmium, these partly pass to the fume and, under oxidizing conditions, form oxides. The fine fume particles combine readily with the sulphuric acid formed, giving rise to sulphates and the consequent neutralization of the acid. The neutralization or the formation of sulphates probably does not readily take place until temperatures below 200° C. are reached, meaning practically that before sulphates are formed the sulphuric acid must be below its condensation point.

There seems little doubt that some sulphates will form at temperatures above 200°.

Certain theoretical considerations and facts of observation support to some degree the method of formation of sulphates here suggested. Sulphates would not be expected in deep-seated rocks, and apparently they are absent. They might form in low-temperature magmas, but their abundant formation in such magmas would not be expected, and this seems to agree with observations. On the cooling of certain mixtures of gases, the formation of sulphur trioxide would be expected, and under certain conditions the formation of sulphates, and this seems to accord with the facts of observation.

The fact must not be overlooked, however, that the sulphates under discussion are associated with sulphides and were apparently deposited at the same time. The method would appear to make it necessary to suppose that sulphides were deposited in the presence of free oxygen.

We may next assume that free oxygen does not occur in the assumed magmatic emanation and see if there is an available supply of combined oxygen for oxidation of sulphur to form sulphuric compounds. There seems ample evidence to indicate that the oxygen present in the magma and in the surrounding mineralized zone is not sufficient to insure that all the elements will be in their highest state of oxidation. It is sufficient, however, to insure that much of the iron in igneous rocks may be present as ferric compounds, notably magnetite and hematite. In fact, ferric iron is an important constituent of most igneous rocks, and in the contact deposits and veins formed at high temperatures ferric iron is abundant in the minerals magnetite, hematite, garnet (andradite), and other ferric compounds.

In deposits formed at lower temperature ferric minerals are far less abundant and may be entirely absent, the iron present being in ferrous minerals or in sulphides and allied compounds. Of veins formed at intermediate temperature Lindgren[4] says:

Scarcely ever do we find the oxides, such as magnetite, specularite, and ilmenite. The predominating gangue mineral is quartz, but carbonates are also common, such as calcite, dolomite, and ankerite, more rarely siderite; fluorite and barite are occasionally of importance.

In veins that contain abundant sulphates the ferric minerals seem to be at least unusual, though ferrous minerals—siderite or ankerite or manganous minerals—as rhodochrosite or rhodonite may be abundant. Thus in the

[1] Knopf, Adolph, Some cinnabar deposits in western Nevada: U. S. Geol. Survey Bull. 620, p. 64, 1916.

[2] Ransome (op. cit., p. 195) suggests sulphuric acid as a precipitant.

[3] Fulton, C. H., Metallurgical smoke: Bur. Mines Bull. 84, pp. 25-26, 1915.

[4] Lindgren, Waldemar, Mineral deposits, p. 514, New York, 1913.

Cocur d'Alene district, Idaho, Ransome [1] found that magnetite with garnet is confined largely to the "contact" type of deposits. In most of the veins of the district ferric minerals are absent, though siderite is abundant. Barite is locally abundant.

Spencer [2] recognizes a transition in the so-called "contact" deposits of the Santa Rita district, New Mexico, from a zone near the intrusive rock characterized by garnet (andradite) to one characterized by manganiferous siderite and hedenbergite—that is, an inner zone where ferric iron predominates and an outer zone where ferrous iron predominates. No sulphates are recognized in these zones. Primary ferrous and manganous minerals in abundance are associated with some of the large ore deposits that are believed to have formed at intermediate temperatures, such as those of Leadville, Gilpin County, Rico, Lake City, and Creede, Colo., Butte and Philipsburg, Mont., and many others. Barite is present in some of the deposits, but it has not been reported from others. It is abundant in some deposits, as those of the Tintic district, Utah,[3] where ferrous and manganous minerals are not abundant, though iron sulphide is plentiful.

The Cactus mine, Utah,[4] appears to offer a good example of the relation of ferric, ferrous, and sulphate minerals. In that deposit hematite was abundantly formed. After its deposition had ceased siderite, anhydrite, and barite were deposited. (See fig. 55.) Pyrite and and chalcopyrite were deposited throughout the period.

From a consideration of igneous rocks and different types of ore deposits, it would appear that ferric iron is common and ferric minerals form in nearly all magmas and their emanations. Sulphur, on the other hand, does not tend to form combinations that crystallize from magmas. Under some conditions sulphur combines with the metals as sulphides in magmas and may form large deposits or it may be oxidized to sulphate, which may then produce complex silicate-sulphate minerals.

[1] Ransome, F. L., Geology and ore deposits of the Coeur d'Alene district, Idaho: U. S. Geol. Survey Prof. Paper 62, p. 94, 1908.

[2] Spencer, A. C., personal communication.

[3] Lindgren, Waldemar, and Loughlin, G. F., Geology and ore deposits of the Tintic district, Utah: U. S. Geol. Survey Prof. Paper 107, p. 153, 1919.

[4] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, p. 121, 1913.

In the contact zone and the deep-vein zone the higher oxide of iron continues to be stable, and ferric minerals as oxide and silicate are abundantly deposited. Sulphur combines with the metals to form sulphides, but the sulphides are in large part later than the ferric oxides and silicates. The sulphate radicle is rarely present and only in silicate minerals. As no insoluble sulphites are formed there is no record as to the presence or absence of the sulphite radicle in the solutions that formed the contact minerals. In veins formed at intermediate and low temperatures ferric minerals are very scarce or absent, whereas ferrous minerals in some deposits are abundant. Sulphides are abundant, and the presence of barite, which is by far the most insoluble of the sulphates, indicates that sulphates probably formed relatively abundantly, but for the most part were carried away in solution.

This change from ferric to ferrous minerals, together with the appearance of sulphate minerals associated with the ferrous minerals, may be interpreted as indicating that at the higher temperatures the conditions were favorable to the oxidation of iron and the reduction of sulphur, whereas at the lower temperatures the conditions were favorable to the reduction of ferric compounds and the oxidation of the sulphur. This interpretation agrees with the experimental data so far as the oxidation of sulphur dioxide and the reduction of ferric compounds are concerned. Possibly this reduction of the ferric compounds takes place to some extent even after the ferric minerals have been deposited from the ore-bearing solutions. The hematite in the Cactus mine, which has already been mentioned, is distinctly magnetic and may have become so by the partial reduction of ferric oxide when sulphur or its compounds were oxidized to sulphuric compounds. This record of the ores, then, reveals one possible source of oxygen to form sulphates apart from free oxygen in magmatic emanation. If a large part of the iron in the magma is in ferric and ferrous oxide, the combination of part of the iron with sulphur to form pyrite would greatly reduce the amount of sulphur and at the same time would furnish oxygen to oxidize the excess of sulphur. It has already been pointed out that the iron in the wall rock of many veins as ferrous and

ferric oxide has combined, in part at least, with sulphur and thus freed the oxygen to go into some other combination.

The deposits of native copper at Corocoro, Bolivia, are worthy of note in this connection. The deposits are in a series of red sediments. The ore solutions have apparently reduced the ferric iron in the beds containing the ores, and sulphates have been deposited. Miller and Singewald[1] say:

> The mineral solutions that circulated through the ore beds have bleached them to a white or light green color, but the impervious shales between have not been affected by the solutions. Patches of red sandstone within the ore bodies that have been protected from the bleaching action of the mineralizers are barren of ore. * * * * Gypsum and, less abundantly, barite and celestite occur as gangue minerals.

Steinmann, according to Miller and Singewald[2] believes that

> The mineralizing solutions were analogous to those that formed the other copper deposits of the Andes—that is, characterized by the presence of sulphur and arsenic to the subordination of oxygen. On coming in contact with the ferric oxide of the red beds, they reduced it and bleached those strata, and the sulphur was oxidized to sulphuric acid. On account of the greater affinity of sulphuric acid for lime, magnesium, and iron, the sulphates of these metals were formed and copper was set free.

There is evidence that many of the elements in the magmas besides iron were combined with oxygen and that with decrease in temperature they tended to combine with sulphur. The remarkable deposits at Franklin Furnace, N. J.,[3] are instructive in this connection. There was probably a lack of sulphur in the emanations that formed the deposit, and under those conditions manganic minerals were deposited. Zinc was deposited abundantly as oxide and silicate. In deposits containing sulphides manganic minerals are certainly rare, though manganous minerals may be abundant and under some conditions manganese sulphide has been deposited. Likewise if sulphur is present in the emanations the zinc oxide and silicate apparently are never deposited, but zinc at the temperature at which it will be deposited combines with the sulphur.

It may also be noted that tungsten is most commonly deposited as tungstate, but it may be deposited as sulphide. The only known occurrence of the sulphide, that in the Emma mine, Utah,[4] is a deposit that is believed to have been formed at moderate temperature. Here the sulphide of tungsten was one of the latest minerals to form and apparently, in part at least, replaced earlier sulphides.

Tin is commonly deposited as the oxide, but in some of the Bolivian deposits which seem to have been formed at only moderate temperatures and in which sulphides are relatively abundant the sulphide of tin was deposited. Some of these deposits contain barite.

Lunge[5] states that "on boiling sulphur with water, hydrogen sulphide is evolved and sulphuric acid is found in the residue." The formation of sulphuric acid by heating sulphur with water has been demonstrated by Allen,[6] thus hydrogen under certain conditions gives up its oxygen, and the oxygen so released goes to oxidize sulphur. The production of sulphuric acid[7] by the reaction of sulphur dioxide and water at about 150° C. will also take place[8] according to the equation $3SO_2+2H_2O=2H_2SO_4+S$. The resulting sulphur would of course be available for reaction with water under proper conditions for producing sulphuric acid (H_2SO_4).

If it is granted that sulphates form in the zone of intermediate temperatures without the influence of surface agencies, the question then arises whether a similiar origin can be attributed to alunite deposits. There seems to be universal agreement among geologists that alunite deposits have been formed near the surface and also that some of them, at least, are formed by acid solutions that result from surface oxidation. It is manifestly difficult to prove the part that surface and deep-seated agencies have played under such conditions, but if barite, anhydrite, and celestite can and do originate from deep-

[1] Miller, B. L., and Singewald, J. T., The mineral deposits of South America, p. 92, New York, McGraw-Hill Book Co., 1919.

[2] Idem, p. 94.

[3] Spencer, A. C., U. S. Geol. Survey Geol. Atlas, Franklin Furnace folio (No. 161), 1908.

[4] Wells, R. C., and Butler, B. S., Washington Acad. Sci. Jour., vol. 7, pp. 596-599, 1917.

[5] Lunge, George, op. cit., vol. 1, pt. 1, p. 17.

[6] Allen, E. T., personal communication.

[7] Randall, M., and Bichowsky, R. V., Equilibrium in reaction between water and sulphur at high temperatures; The dissociation of hydrogen sulphide: Am. Chem. Soc. Jour., vol. 40, p. 368, 1918.

[8] Lewis, G. N., Randall, M., Bichowsky, R. V., A preliminary study of reversible reactions of sulphur compounds: Am. Chem. Soc. Jour., vol. 40, p. 356, 1918.

seated solutions without surface oxidation there seems to be no good reason why alunite might not also and why this mode of origin may not be considered if it seems to accord best with the observed facts.

The occurrence of hinsdalite as a primary mineral in deposits that are believed by the geologists who have described them to be of deep-seated (hypergene) origin is of interest. This mineral is chemically closely allied to alunite—in fact is a member of the alunite group of minerals—and if it can form from the same solutions as sulphides, rhodochrosite, and barite there seems to be no inherent reason why alunite might not also form from ascending solutions under the proper physical conditions.

The evidence in the field indicates that alunite can form only at low temperatures, probably considerably below the initial temperature at which sulphuric acid and the sulphates of potassium and aluminum may appear in the solutions.

The mineralogically allied minerals of the jerosite groups and other allied basic ferric sulphates are apparently formed only by surface solution, and under near-surface conditions favorable for oxidizing iron, where they may form abundantly. It is obvious that they can form only under conditions favorable to the stability of the higher oxides of both iron and sulphur, and it appears that alunite forms under conditions that favor the reduction of the higher oxide of iron to ferrous compounds or sulphide, on the one hand, and that favor the formation of the higher oxide of sulphur, on the other hand.

The fact that ore solutions may change their character during the deposition of the ore has been long recognized.

Thus Lindgren,[1] in describing the alteration of the rocks adjacent to the veins in the De Lamar mine, Idaho, states:

This confirms the view set forth that two different processes have been active—first, an ordinary process of sericitization, accompanied by a vein filling of barite and calcite, effected by waters containing alkaline carbonates; second, pseudomorphic replacement of the filling by quartz and leaching of Al_2O_3 from the sericitized country rock by siliceous (probably acid) waters.

Lindgren[2] also states that "the loss of so much Al_2O_3 can be explained on the supposition that the waters contained sulphuric acid, as only such thermal waters are known to dissolve alumina in large quantities." In another work he says:[3]

Veins formed near the surface in volcanic regions are sometimes subject to peculiar changes, which are rarely observed in deposits of more deep-seated origin. An earlier gangue mineral, such as calcite or barite, may be wholly wiped out and replaced by a new gangue of quartz and adularia. This alteration has nothing to do with surface waters; it is plainly caused by a change in the composition of ascending current.

In the San Francisco district, Utah, there is a notable difference in the alteration of the wall rock and in gangue minerals in neighboring deposits in Tertiary lavas, which, it is believed, represent different stages in the process of ore deposition. Thus regarding the Horn Silver and Beaver Carbonate mines, it is stated.[4]

Although the principal ore minerals of the two deposits are the same there is a notable difference in the gangue minerals. Carbonates are important in the Beaver Carbonate mine and sulphates in the Horn Silver mine. This difference points to a difference in the character of the solutions that deposited the ores, and a similar difference is indicated in the alteration of the rock adjacent to the deposits. The extensive removal of alumina from the rock of the Horn Silver deposit and the presence of abundant sulphates is contrasted with the failure to remove alumina and the presence of calcite in the Beaver Carbonate deposit.

The presence of sulphuric acid in solutions that deposited sulphides is suggested by Spurr. Concerning the alterations of the wall rocks at Tonopah, Nev.,[5] he says:

However, they [the mineralizing solutions] attack the rock vigorously by virtue of the carbonic acid, probably also sulphuric acid, and perhaps to a less extent by acids of chlorine and fluorine.

The many known reversible reactions that go on with changing conditions make the problems of changes in ore solutions most complex. These problems really belong in the field of chemistry, but as the reactions that go on in ore solutions as a result of changes in temperature and in concentration

[1] Lindgren, Waldemar, The gold and silver veins of Silver City, De Lamar, and other mining districts in Idaho: U. S. Geol. Survey Twentieth Ann. Rept., pt. 3, p. 182, 1900.

[2] Idem, p. 181.

[3] Lindgren, Waldemar, Mineral deposits, p. 436, New York, 1913.

[4] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, p. 133, 1913.

[5] Spurr, J. E., Geology of the Tonopah mining district, Nev.: U. S. Geol. Survey Prof. Paper 42, p. 234, 1905.

may exert a large influence on the deposition of the ores, the geologist may properly point out some of the facts that need explanation and indicate the evidence of the changes that have taken place as it is preserved in the rocks and ores. There are undoubtedly changes of which no record remains; indeed, were it not for the presence in ore deposits of a few sulphates that are relatively insoluble, there would be little record of the existence of the sulphate radicle in ore solutions from deep sources. In this discussion attention has been directed to some possible relation of sulphur and oxygen to other constituents of ore solutions, but it is obvious that other elements should be considered, especially carbon.

The possibility of the formation of sulphuric acid and sulphates in magmatic emanations may have a bearing on many problems, but it is not the purpose to pursue their study here. It may, however, be pointed out that close observation of the relations of minerals is essential to a clear understanding. It seems certain that although barite, for instance, does not form at high temperature, it may be associated with minerals that were formed earlier at high temperature, or even later, as when once formed and perhaps covered with other minerals it might persist, even though the temperature might be raised.

A student of copper deposits who considers the possibility of a deep-seated source of sulphuric acid will read with added interest the paper by Zies, Allen, and Merwin[1] on reactions between copper sulphate and sulphuric acid and various sulphides at moderately high temperature. It seems that there is an almost unlimited field for similar investigations which will contribute directly to the solution of some problems of ore deposition.

SUMMARY.

Sulphates in igneous rocks and in deposits formed at high temperature are confined to a few complex silicate minerals that contain the sulphate radicle. In deposits formed at intermediate temperature barite is common and anhydrite and celestite are not uncommon. Under favorable conditions, and probably at comparatively low temperature, alunite forms abundantly. In some deposits at least the sulphate of the alunite was probably derived from deep-seated solutions.

A study of volcanic emanations has shown that they exhibit changes in character and that in the later stage of fumarolic activity they may contain sulphurous and sulphuric compounds. Sulphuric acid can readily be formed by the reducing action of sulphur dioxide on ferric solutions. If igneous emanations contain free oxygen and sulphur or sulphur dioxide it would be expected that as they became cool sulphur trioxide would be formed and that at suitable temperature the sulphates would be formed. Sulphur trioxide is unstable at high temperatures, and the temperature range in which it forms rapidly and is stable is narrow. If emanations contain no free oxygen, that combined with the metals or with hydrogen at high temperatures may at lower temperatures combine with sulphur to form the oxides of sulphur and sulphuric compounds. This interchange of oxygen from certain elements at high temperature to sulphur at lower temperature is believed to be an important factor not only in the formation of sulphates in solutions of deep-seated origin but also in the precipitation of primary (hypergene) ore minerals.

ACKNOWLEDGMENT.

In closing the discussion of this subject the writer wishes to acknowledge gratefully the criticisms and helpful suggestions of coworkers on ore deposits, especially those of E. S. Bastin, Adolph Knopf, E. S. Larsen, G. F. Loughlin, Chase Palmer, F. L. Ransome, Max Roesler, A. C. Spencer, and R. C. Wells, of the United States Geological Survey; Drs. E. T. Allen, J. B. Ferguson, and R. B. Sosman, of the Carnegie Institution of Washington; and Prof. John Johnson, of Yale University, without implying, however, that all these students subscribe to all the ideas here put forward.

AGE OF DEPOSITS ASSOCIATED WITH IGNEOUS ROCKS.

The age of the deposits associated with the igneous rocks is essentially that of the igneous rocks to which they are related in origin. (See p. 99.) So far as has been definitely shown, the main igneous activity began in post-Cretaceous time and may have continued through much of Tertiary time. Possibly some of the igneous

[1] Zies, E. S., Allen, E. T., and Merwin, H. E., Some reactions involved in secondary copper sulphide enrichment: Econ. Geology, vol. 11, pp. 407-503, 1916.

bodies and the associated ore deposits in the western part of the State are Cretaceous or older. A few deposits in the Wasatch and Uinta ranges appear to be of pre-Cambrian age.

RELATION OF ORE DEPOSITS TO DIFFERENT TYPES OF INTRUSIVE BODIES.[1]

The ore deposits associated with igneous rocks present especially favorable opportunities for observations on the relations of ore deposition to different types of intrusive rock bodies. This is due in no small part to block faulting since intrusion, which (along the Wasatch front and the west side of the Mineral Range, for instance) has brought into the field of observation bodies intruded at greatly differing depths. The small size of all of the intrusive bodies in comparison with those in California, Idaho, and Montana is also favorable to such a study.

NOMENCLATURE.

The intrusive bodies may be divided into laccoliths and stocks. (See p. 91.) The stocks differ according to the distance below their tops to which they have been eroded and may be designated apically truncated stocks, or those cut by the present erosion surface not far below the original top; medially truncated stocks, or those cut much farther below the original top; and deeply truncated stocks, or those cut to still greater depths. It is apparent that the erosion surface may have reached the zone of mineralization induced by a stock without having exposed the stock itself. Such conditions may be present in Utah in the Gold Springs-State Line area, at Ophir, and at other localities.

The medially truncated stocks probably comprise more than 75 per cent of the area of the exposed intrusive masses and are nearly equal in number to the other types. The apically truncated stocks and laccolithic bodies are each represented in several places, the apically truncated stocks being both areally and numerically most important.

The geologic map (Pl. IV, in pocket) shows the number and location of the different intrusive bodies in the State and in a general way the relative sizes of the different intrusive bodies in the western part of the State. The individual members of the laccolithic groups of eastern Utah are too small to have their relative sizes even approximately shown on a map of the scale used.

[1] The essential features of this discussion were published in Econ. Geology, vol. 10, pp. 101-122, 1915.

MINERALIZATION ASSOCIATED WITH DIFFERENT TYPES OF INTRUSIVE BODIES.

GENERAL FEATURES.

With the relative abundance of the types in mind it is somewhat surprising that not a single mine of first or even of second class importance is associated with either the medially truncated stocks or the laccolithic bodies. Of the total metal output of the State, valued at over $916,000,000 to the end of 1917, less than one-half of 1 per cent has been derived from deposits associated with these two types; and it is certain that the commercial importance of both has been negative; that is, that more has been expended on them than has been realized from them.

The deposits in the western part of the Little Cottonwood district may possibly be associated with the Little Cottonwood stock instead of the Alta-Clayton Peak stock, in which case this statement would have to be somewhat modified; but in any case the mineralization either in the Little Cottonwood stock or in the associated pre-Cambrian rocks is trifling as compared with that in the early Paleozoic rocks of the Little Cottonwood district and in the late Paleozoic and early Mesozoic rocks of the Park City district. On the other hand, important ore bodies are associated with nearly every one of the apically truncated stocks, and it is from these bodies that the great bulk of the metal output of the State has been derived.

LACCOLITHS.

Mineralization associated with the laccoliths consists of small gold-copper veins in the larger laccoliths and a little contact mineralization in adjacent calcareous sediments. Practically no mineralization is associated with the smaller laccolithic bodies.

STOCKS.

Medially truncated stocks.—Mineralization is slight in the more deeply truncated stocks. Pegmatitic gold quartz veins extend from the Ibapah stock into the adjacent quartzites. Galena-fluorite veins are present in the Granite Range stock and quartz-fluorite pyrite veins

in the Sheeprock Mountains stock. Small veins said to contain copper are reported from the Mineral Range stock, copper-molybdenite veins occur in the Little Cottonwood stock, and similar veins are present in some of the other deeply eroded stocks.

Contact deposits and replacement veins in the adjacent sedimentary rocks are associated with practically all the stocks, especially with that of the Mineral Range, but none of them are large.

Apically truncated stocks.—Extensive fissure and replacement fissure deposits are present in practically all the apically truncated stocks. Quartz-tourmaline copper replacement veins are present in the San Francisco and Clifton stocks; tourmaline-scheelite pegmatitic veins or dikes in the Clifton stock; biotite-orthoclase-sericite copper deposits in the Bingham Canyon stock; lead-silver-zinc veins in the Bingham Canyon stock; and lead-silver and gold-copper veins in the Tintic stock. Few deposits have been extensively worked in the Park City stocks, though lead-silver veins have been followed from the sedimentary into the intrusive rock.

The adjacent sedimentary rocks have undergone intense contact metamorphism near the San Francisco, Clifton, Clayton Peak, and Iron Springs stocks, and less intense metamorphism near the Bingham, Tintic, and other stocks. Replacement veins, which are present in the rocks adjacent to all the stocks, have yielded large amounts of lead, copper, silver, and zinc, and to the present time have been the most productive type in the State. Associated with the stocks in the southern belt are deposits in the extrusive rocks that have yielded important amounts of lead, zinc, copper, and precious metals.

SUMMARY.

Mineralization associated with the laccoliths is not extensive and is largely confined to the intrusive bodies, though slight mineralization has occurred in the adjacent sedimentary rocks.

Mineralization associated with the medially truncated stocks is comparatively slight and is present both in the intrusive bodies and in the adjacent rocks. That in the intrusive bodies is prevailingly of the deep-seated type, approaching pegmatite in character, as is shown by the pegmatitic gold quartz veins of the Ibapah stock. Mineralization in the adjacent sedimentary rocks is most important in the Mineral Range, where limestone is present—a fact that has doubtless influenced the extent of mineralization. (Most of the deeper-truncated stocks are in contact with the siliceous early Cambrian and pre-Cambrian rocks.) That the character of the inclosing rock has not been the determining factor in the mineralization is indicated by the important deposits that occur in siliceous sediments and extrusive rocks associated with apically truncated stocks, as in the Bingham, Park City, San Francisco and other districts; and by the small importance of the deposits in the limestone of the Mineral Range as compared with those of the Star and Park City districts, which occur in sedimentary rocks of essentially the same age and character associated with apically truncated stocks.

Mineralization associated with the apically truncated stocks is extensive both in the intrusive rock and in the adjacent sedimentary and extrusive rocks. The mineralization in the stocks is prevailingly of the high-temperature type, though the lead-silver veins of the Tintic and Bingham districts indicate formation at only moderate temperature and pressure. In the sedimentary and effusive rocks the mineralization shows more or less complete gradation from the high-temperature contact type to fissure deposits formed at moderate and comparatively low temperatures.

CAUSES OF DIFFERENCES IN MINERALIZATION.

LACCOLITHS.

The material forming the laccolithic bodies entered the space occupied through a relatively narrow channel. As soon as the active flow through this passage into the laccolithic chamber ceased, the material in the passage quickly solidified, effectively sealing off the laccolith from the deeper source from which its material had been derived. If the body was small the solidification was rapid and there was little opportunity for differentiation. Some of the smaller laccolithic bodies have almost the texture of lava and evidently afforded little more opportunity for differentiation than a surface flow. If the mineralization associated with the igneous rocks was, as the writer holds, a late phase of their differentiation, it is not

surprising to find that practically no mineralization, either in the igneous masses or in the adjacent sedimentary rocks, is associated with these small undifferentiated laccoliths.

In the larger laccoliths solidification proceeded more slowly. The resultant rocks are much more coarsely crystalline and in some of them a few dikes are present. The presence of these dikes may indicate that crystallization was slow enough to permit the crystallizing mass to separate into portions of different composition, and that before the entire mass had solidified portions had become sufficiently solid to fracture as a result of the stresses set up in the cooling and solidifying mass, and that the more fluid portions had been forced into these fractures and formed dikes therein. Mineralization in these larger laccoliths occurs along fissures in the intrusive rock and in the sedimentary rocks adjacent to the intrusives. It seems reasonable that the mineralizing solutions, like the dikes, should have separated from the crystallizing magma and have passed along fissures into the solidified portions, where they deposited the ore minerals, or have escaped into the adjacent sedimentary rocks, where they formed the contact deposits.

On the assumption that the ore solutions have resulted from a differentiation of the magma within the laccolithic reservoirs, certain deductions concerning the probable size and abundance of the ore deposits are possible. In the smaller outlying reservoirs, where solidification was so rapid that there was little opportunity for a differentiation of the magma, there was little possibility for the different materials to collect in bodies of any considerable size. In the larger bodies, where the solidification was slower, the opportunity for separation was more favorable, but even in the largest of the laccoliths in southeastern Utah solidification must have been so rapid that in a large part of the material there would be little opportunity for differentiation and in the remaining portion conditions would not be favorable to a high degree of differentiation. It may be presumed then that in the crystallization and solidification of these rock masses the proportion of the metals expelled was small when compared with what would have been expelled under conditions of slow crystallization that gave ample time for separation and segregation of the constituents.

It should be remembered also that laccolithic bodies are usually cut off from their deep-seated source and that in them there is no tendency to concentrate the more mobile substances resulting from deeper-seated differentiation.

Movements of the rocks might conceivably keep open the supply channels to some of the deeper igneous reservoirs, thus permitting the entrance of mobile constituents from below and the formation of large ore deposits, but no known evidence indicates that this has taken place in any of the laccoliths of Utah.

If the above suppositions and deductions are correct the extent of the ore deposits associated with laccolithic bodies, other things being equal, is dependent on the size of the laccolith. If it is small, there will likely be no mineralization; if very large, extensive deposits might be expected. In the laccolithic groups of southeastern Utah the total amount of igneous material is considerable, but that contained in any individual laccolithic body is relatively small. From theoretical considerations, then, it is to be expected that only small metal deposits are present in these laccoliths.

Gilbert [1] many years ago arrived at essentially this conclusion, though he based it on the belief that conditions were not favorable to the formation of fissures rather than on the considerations presented above. Since then prospecting has been carried on intermittently for 40 years, and many thousands of dollars have been expended in the search for and development of metalliferous veins. Some have been found and have yielded a little gold, silver, and copper. Those developed to the present time, however, are relatively small and are associated with weak fissuring and give little promise of important production. Gilbert's prediction that "gold and silver will not be found in paying quantities in the laccolithic mountains, including the La Sal, Abajo, and Henry mountains," seems to hold good. The foregoing statements, of course, apply only to lode deposits and not to the sandstone and placer deposits in the vicinity of these mountain groups.

STOCKS.

The space occupied by the igneous material constituting the stocks was probably gained in large part by a pushing aside and doming of the

[1] Gilbert, G. K., Report on the geology of the Henry Mountains: U. S. Geol. and Geog. Survey Rocky Mtn. Region Final Rept., pp. 82-83, 151-152, 1877.

earlier rocks. That there was some stoping and assimilation of the invaded rocks, especially in the deeper portions of the stocks, seems not improbable, though little evidence of it has been observed, and it is not thought to have been important. (See p. 91.)

Daly[1] has pointed out that the diagram (fig. 31, previously published by the writer[2]) may be interpreted as indicating that stoping has been important. This weakness in the diagram is due to the fact that it presents only two dimensions and therefore can not show the displacement of the rocks without great complication, which would obscure its main purpose of showing the position of the ore bodies with reference to the stocks.[3]

The formation of the stocks as they now occur may be thought of as taking place in the following general manner, though the actual process was doubtless more complex. (See also p. 98.)

After the intrusion had taken place crystallization of the fluid magma began, or continued if it had already begun. The higher portions of the intrusive bodies and the whole of the smaller masses lost their heat most rapidly and crystallized most quickly, so that the upper part of a body and the relatively small apophyses underwent comparatively slight differentiation and became sufficiently solid to fracture while the deeper-seated portions were still fluid. This presumes that the rocks now exposed in the apically truncated stocks have a composition nearer that of the original magma than those exposed in the more deeply truncated stocks, an assumption that seems to be borne out in a general way by the composition of the laccoliths, where differentiation was certainly slight. No laccolith has been found associated with a stock where a direct comparison would be warranted.

As crystallization proceeded slowly water and other light and very mobile constituents, with metals, sulphur, silica, and other materials in solution, were expelled from the crystallizing magma and tended to move upward. This movement apparently took place through the fluid with no marked tendency to concentration other than a convergence as the size of the stock decreased upward, or to migration into the inclosing walls. When the material was sufficiently crystallized and solidified, fracture formed, in which these mobile constituents concentrated and passed on into cooler portions of the intrusive body or into the inclosing rocks. When the physical-chemical conditions were favorable to the precipitation of metals the formation of ore bodies began. In the intrusive bodies the tourmaline veins formed first and copper-gold and lead-silver veins later. As the solutions passed from the intrusive bodies into the inclosing sedimentary and extrusive rocks under differing chemical and physical environments, various types of deposits formed. (See fig. 31.)

If this interpretation is correct fractures in passing downward should disappear at a level where the material was too liquid to retain a fracture at the time they were formed. That such conditions are not more often seen is perhaps due chiefly to the fact that this level was not favorable to extensive mineralization and offers little inducement for economic development, but they seem to be exemplified in the fracture zone of the Cactus mine in the San Francisco stock. At the surface a broad breccia exceeding 100 feet in width is traceable along the strike for several thousand feet. As it passes downward the width contracts and the brecciation decreases until at a depth of 900 feet the width is only a few feet and the brecciation is very slight; at a few hundred feet deeper the fracture may disappear entirely. The early minerals of this deposit, as would be expected, are of the high-temperature type. Similar conditions probably obtain in other deposits in the State, as in the pegmatitic tourmaline veins of the Clifton district, but developments have been too meager to reveal them. Somewhat similar conditions occur where pegmatitic gold quartz veins of the Ibapah stock pass into true pegmatite carrying no metals.

The most important deposits of the State are associated with igneous masses that have been eroded to only a relatively short distance below their top, as those in the Park

[1] Daly, R. A., Ores, magmatic emanations, and modes of igneous intrusion: Econ. Geology, vol. 10, p. 471, 1915.

[2] Butler, B. S., Relation of ore deposits to different types of intrusive bodies in Utah: Econ. Geology, vol. 10, p. 119, 1915.

[3] The manner of intrusion of the Little Cottonwood and Tintic stocks has been described by Loughlin (Econ. Geology, vol. 11, pp. 284-288, 1916) in reply to Daly's criticism above cited. The intrusion process of the Tintic stock has also been more thoroughly discussed by Loughlin (Geology and ore deposits of the Tintic mining district, Utah: U. S. Geol. Survey Prof. Paper 107, p. 87, 1919), who shows that the visible effects of intrusion are due mainly to the thrusting action of the magma, although stoping subsequent to the thrusting was of considerable importance.

City, Bingham, Tintic, San Francisco, and Iron Springs districts, and the Tushar Range. That deposits, now eroded away, comparable in extent with these may have been associated with higher portions of the larger and more deeply eroded masses seems entirely probable, but that such deposits will be found associated with the deeply eroded remnants now remaining seems highly improbable.

This explanation supposes that there was a relatively greater expulsion of metallic constituents from the portions of the magmas that crystallized slowly than from those that cooled rapidly near the surface, and that there was a transfer of metallic constituents from the deeper zone to points nearer the surface—that is, if the different rock bodies were to be sampled it would be found that the disseminated metal content of the rock of the small laccoliths would be highest and would not differ materially from corresponding extrusive rocks; that of the large laccoliths would be less, for part of their metals are collected in veins; that of the apically truncated stocks would doubtless be less than that of the laccoliths, for the conditions under which they consolidated doubtless permitted greater differentiation; and that of the more deeply truncated stocks would be least of all, for in them opportunity was ample for extensive differentiation and for the migration of metallic constituents toward the surface. The process was everywhere the same, differing only in degree.

The general relations and processes here described have for the most part been recognized before, but they are especially well illustrated and their commercial importance is especially well shown in the ore deposits of Utah.

Spencer[1] has pointed out that cross-cutting intrusive bodies are more favorable to ore deposition than sills because of the more direct connection with the deep-seated source. Ferguson and Bateman[2] have shown that tin deposits commonly occur near the top of granite bodies.

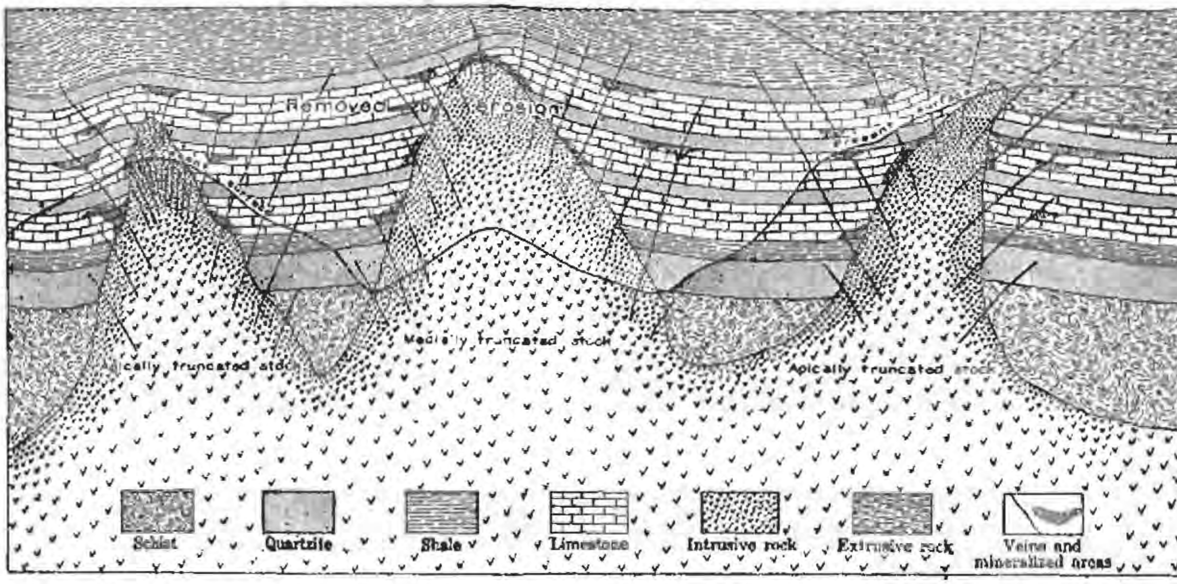


FIGURE 31.—Ideal section through the top portion of an intrusive zone, showing the portions where differentiation became more important and the places where metals were precipitated. The lighter portions of the stock are more highly differentiated in this horizon, being most siliceous.

The general process of differentiation here outlined does not differ materially from those previously suggested, notably by Spurr.[3]

Probably the relations of the intrusive bodies in Utah are unusually simple, owing perhaps to relatively stable conditions following the intrusions. After the magma had been partly solidified and the still fluid part consisted of a siliceous portion underlying the solid and perhaps of a basic portion underlying the siliceous portion, an impulse from below might drive the fluid portions into or through the solidified portions and might even

[1] Spencer, A. C., Magnetite deposits of the Cornwall type in Pennsylvania: U. S. Geol. Survey Bull. 359, p. 16, 1908.

[2] Ferguson, H. G., and Bateman, A. M., Geologic features of tin deposits: Econ. Geology, vol. 7, p. 223, 1912.

[3] Spurr, J. E., Theory of ore deposition: Econ. Geology, vol. 7, p. 485, 1912.

force them to the surface as flows. That such conditions are undoubtedly present in Utah is shown by pegmatitic and basic dikes of the Granite Range, but for the most part they seem to have been of minor importance

It is possible that the concentration of metals near the apex of a stock is influenced by the relation of the magma at the time of intrusion to the surface or to the zone of fracture. If a magma containing gases held in solution under pressure is forced through the overlying rock until it connects with the surface or with the zone of fracture we may imagine a condition similar to that produced by removing the cork from a bottle of champagne, when the dissolved gases move toward the region of lower pressure. In this manner there might be relatively rapid movement of previously dissolved gases into a restricted area from a large volume of magma. The expansion of gases under decreased pressure and chemical reactions would effect temperature changes that may be factors in precipitating metallic and other substances. If the magma did not reach the surface the influence of difference in pressure would not be effective or would be less effective. This may account for the conditions in the Park Valley district and in the Grouse Creek Range, where the intrusive bodies (whether laccoliths or stocks is not apparent), whose tops are exposed by deep erosion, do not appear to contain large deposits of ore. It is not always possible to determine whether an intrusive body was connected with the surface before solidifying. There is, however, evidence that some of the stocks of Utah were so connected, notably those of the Tintic and Marysvale districts. Proof that an intrusive body now exposed had no connection with the surface before solidification is more difficult to discover. There are perhaps some criteria that would aid in such a determination, and their recognition will be valuable. The deep-seated intrusive body of the Park Valley district and the Granite Mountain intrusive mass contain abundant aplite and pegmatite dikes. Possibly the retention of these differentiation products indicates a lack of surface connection. Large ore deposits have not been found associated with these bodies. Whether aplites and pegmatites are significant or not, it may be noted that the intrusive rocks of all the districts containing large ore deposits are similar in character to those that are believed to have had a surface connection before solidification.

SUMMARY.

The larger intrusive bodies of Utah are of two types, laccoliths and stocks. The laccoliths occur in the sandy and shaly sedimentary rocks in the southeastern part of the State, the stocks in the quartzites and limestones in the western part of the State.

The stocks may be subdivided into those truncated near the apex and those truncated at greater depth. The deeper truncated stocks are uniformly the more siliceous. The apically truncated stocks range in composition from monzonite to diorite and the deeper truncated stocks from granodiorite to granite.

Ore deposits associated with the laccoliths and deeper truncated stocks are of comparatively slight commercial importance and those associated with the apically truncated stocks are of great value.

The lack of large deposits associated with laccoliths is probably due to the fact that after intrusion the laccoliths were sealed off from their deep-seated source and that the amount of material in them was too small and the differentiation on solidifying too incomplete to furnish large deposits.

In the stocks the differentiation was probably greater at depth. The water and other lighter mobile constituents of the magma, with metals, sulphur, and other materials in solution, rose toward the surface; and the heavier minerals that crystallized early sank to greater depth. When the mobile constituents reached a portion of the solidified magma that was fractured they were guided by the fissures and on reaching favorable physical and chemical environments began to deposit their metals. The deeper truncated stocks are probably remnants from which the portion in which the metals were concentrated has been eroded.

RELATION OF ORE DEPOSITS TO SEDIMENTARY ROCKS OF DIFFERENT AGES.

Ore deposits occur in sedimentary rocks ranging in age from pre-Cambrian to Tertiary. Deposits of large commercial importance thus far developed are, however, confined to those ranging from Middle Cambrian to Jurassic.

A few small deposits are present in pre-Cambrian rocks in the Simpson Mountains (Erickson district), Sheeprock Mountains (Blue Bells district), northern Wasatch area, in the Santaquin region, and in the Browns Park region (Uinta Mountains). Deposits in Tertiary rocks, so far as known, are confined to copper deposits in the Ouray region and lead-zinc-copper deposits in the Salina Creek district. No metallic deposits are known in rocks of Cretaceous age. Placer deposits occur in the Quaternary sediments.

Deposits in Cambrian rocks occur in the Little and Big Cottonwood, American Fork, Promontory, Ophir, and Tintic districts, in the Mount Nebo-Santaquin region, in some of the districts west of Tintic, in the Deep Creek Range, and in the Pine Grove district. The most important deposits are in the Tintic, Ophir, Cottonwood, American Fork, and Promontory districts. In the Ophir, Cottonwood, and Promontory districts important deposits occur in the Middle Cambrian shale-limestone series. In the Tintic district important mineralization is present in Upper (?) Cambrian dolomite, the Centennial-Eureka mine being in rocks of that age.

The most valuable deposits in the Ordovician to Devonian rocks are in the Tintic and Fish Springs districts; less valuable ones are in the Santaquin-Mount Nebo and San Francisco districts.

The most extensive deposits in the lower Carboniferous rocks are in the Tintic, Ophir, Mercur, Camp Floyd, and Cottonwood districts; less extensive ones are in the North Tintic, Provo, Santaquin-Mount Nebo, San Francisco, and Clifton districts. The most valuable deposits in the upper Carboniferous rock are in the Park City, Bingham, Lucin, and Star districts in the Mineral Range and the Iron Springs district; less valuable ones are in the Clifton district.

Deposits in the Triassic rocks occur in the Park City and Star districts and in some of the "Red Beds" deposits of the Plateau region, the most important deposit of this type being the Silver Reef.

Deposits in Jurassic beds occur in the Tushar Range and in the Plateau region, where they include many of the uranium and some of the copper and manganese deposits.

The deposits in the sedimentary rocks are mainly in limestone and dolomite. (See p. 174.) The age of the formation appears less significant economically than the composition and relations of the limestone and the character of the associated intrusive rocks. Age alone gives no definite measure of the depth to which a formation was buried at the time of the deposition of the ores; for previous to the great igneous activity of Tertiary time an old erosion surface cut all the earlier formations in the western part of the State, and Tertiary extrusive rocks lie unconformably on all formations from early Paleozoic to Tertiary.

ALTERATION OF THE ORE DEPOSITS BY SURFACE AGENCIES.[1]

IMPORTANCE.

All of the ore deposits have been changed to a greater or less extent by the action of surface agencies, mainly of meteoric water carrying materials in solution. The effects differ greatly both in amount and character in the different types of ore deposits. The magnetite-hematite iron deposits, for example, have been but slightly affected either in character or in value, but some of the copper and zinc deposits owe their commercial importance to the action of surface agencies.

Economically the alteration of the ores has been important, first, by effecting a partial segregation of the individual metals or groups of metals of the original deposits; and second, by greatly simplifying the necessary metallurgic treatment. The extensive development of the mining industry of the State would doubtless have been much delayed had it not been for the existence of large bodies of oxidized ores that readily yielded to the simple metallurgic treatment of the early days. Methods of treating the complex primary ores have been developed slowly and even now are only partly successful.

[1] No complete discussion of this subject is intended. Those especially interested should consult Emmons, W. H., U. S. Geol. Survey Bull. 625, 1917, in which a general discussion and references to the extensive literature may be found.

CONDITIONS INFLUENCING SURFACE ALTERATION.

GROUND-WATER LEVEL.

The ground-water level is perhaps the most important factor in the superficial alteration of the ores, for in many deposits it approximately marks the line to which alteration has progressed and beyond which it has usually not extended far. The position of ground-water level varies greatly with the precipitation, structure, and other conditions of the region.

The movement of ground waters has been discussed by numerous authors.[1] Finch has separated the area affected by surface waters into the gathering zone, extending from the surface to the water table; the zone of discharge, the portion of the saturated zone in which the movement of the water is well

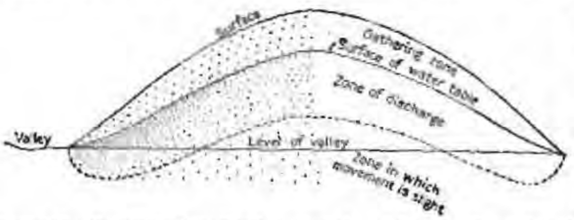


FIGURE 32.—Generalized vertical section along a fissure outcropping at different elevations, showing the distribution and flow of the waters in the fissure. The shading indicates the variation in amount of flow at different points.

marked, extending from the top of the water table to the lowest level from which horizontal discharge is ordinarily possible; and the static zone, in which the movement of the water is ordinarily infinitesimal.

The position of these zones in a vein that outcrops at different levels, for example, one extending from a valley through a ridge to a second valley, is shown in figure 32. Conditions of circulation and consequently of oxidation at given distances below the surface are evidently materially different on the divide and in the valleys. The zone above the water table is materially thicker near the divide, and the active circulation of water probably extends much farther below the top of the water table on the divide. The actual thickness of the zones, especially those of the gathering zone and the zone of discharge, is dependent to a large extent on the amount of precipitation. For example, the heavy precipitation in the Wasatch Range causes the water table to stand only a few hundred feet below the surface, even near the divides and in readily permeable formations; whereas in some of the ranges in the central and southwestern part of the State, where precipitation is slight, the top of the water table lies very deep. In the Tintic district it is 1,600 to 1,800 feet below the valleys and 2,100 to over 2,300 feet below the higher ground.

Usually a single vein or fissure does not extend for a great distance, and the height of the water table in the vein is dependent in large part on the permeability of the rock in which it occurs. This difference is well illustrated in areas of igneous rocks adjacent to limestones and quartzites, the water table in the igneous areas commonly being much nearer the surface, as in the Tintic district, where permanent water is reached only 300 to 800 feet below the surface in the igneous rocks but is very much lower in the adjacent sedimentary rocks. Similar conditions occur in the San Francisco district; in the volcanic rocks about Frisco the water level is but a few feet below the surface, whereas in the Horn Silver mine on the contact of limestone and volcanic rocks it lies at a depth of more than 1,000 feet.

To various combinations of the conditions outlined above are due the great differences in the depths to which there is active circulation of oxidizing waters in the different deposits and consequently in the depths to which the ore deposits have been altered.

A further complication in the area within the Great Basin is that at earlier periods the water level has stood higher and probably also lower than at present. Shore lines on the sides of the basin show that the waters once rose approximately 1,000 feet above the present level of Great Salt Lake, and alluvial cones traceable nearly to the lowest points of the basin suggest that at some time the waters may have been lower than at present.[2]

These differences in the accumulation of waters in the inclosed basin indicate climatic variations, though such were probably slight.

[1] Slichter, C. S., Theoretical investigation of the motion of ground waters: U. S. Geol. Survey Nineteenth Ann. Rept., pt. 2, pp. 297-384, 1899.

Van Hise, C. R., A treatise on metamorphism: U. S. Geol. Survey Mon. 47, pp. 571-576, 1904.

Finch, J. W., The circulation of underground aqueous solutions and the deposition of lode ores: Colorado Sci. Soc. Proc., vol. 7, pp. 193-252, 1904.

[2] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, pp. 90, 220, 1890.

A small increase in precipitation or decrease in evaporation would account for the change. The readiness with which the level of the Great Salt Lake responds to climatic changes is shown by fluctuations of more than 15 feet that have been recorded since 1850, the higher levels corresponding to periods of relatively high precipitation and the low to periods of low precipitation.[1] (See Pl. XXII.) Evidently the balance between accumulation and evaporation in the basin is very close, and a very slight increase in precipitation or decrease in evaporation over a long period would cause an important rise in the lake level. That the climatic conditions at the time of the higher lake stages were not very different from the present is indicated by the fact that only basins fed by streams draining high mountain areas contained such lakes.[2]

The effects, therefore, during the higher lake stages on deposits at high elevations did not differ greatly from the present ones, for the deposits were too high above the lake to be much affected by its rise and fall and the precipitation was much the same. In the higher areas the chief changes were probably due to erosion by the glaciers that doubtless formed at that time in a few of the ranges. In the lower areas, however, the effect was pronounced. The rising of the water level of the lake 1,000 feet might cause as a maximum an equal rise in the water table in certain veins and an important change in many of the veins in the lower ranges.

In some of the deposits in the lower ranges the ores are oxidized considerably below the present water level and it seems not unlikely that the alteration occurred while the waters in the basins were lower than at present and probably before the sediments had accumulated in the basins to the present level. The water level in the veins in limestone in the Tintic district is only slightly above the level of Utah Lake, but oxidation has evidently extended considerably below this level, and a similar condition is true of the water level and oxidation in the Star district.

[1] Henshaw, F. F., Porter, E. A., and Stevens, G. C., Surface water supply of the Great Basin: U. S. Geol. Survey Water-Supply Paper 330, pl. 3, 1914.

[2] Gale, H. S., Notes on the Quaternary lakes of the Great Basin, with special reference to the deposition of potash and other salines: U. S. Geol. Survey Bull. 540, p. 399, 1914.

EROSION.

The rapidity of erosion has an effect on the depth to which alteration extends. If erosion is rapid oxidation may be able to keep only a short distance in advance of it and will be shallow. On the other hand, if erosion is very slow oxidation may reach far below it.

Ordinarily the higher the elevation the more rapid the erosion, but in Utah precipitation is so great on the higher areas, as the Wasatch and Uinta ranges, that they support a dense vegetation which retards erosion and partly offsets the heavier precipitation and greater elevation. Moreover, the high areas are less subject to the torrential rains that from time to time accomplish such rapid erosion in the comparatively bare desert ranges. In small areas that extend above timber line erosion is very rapid.

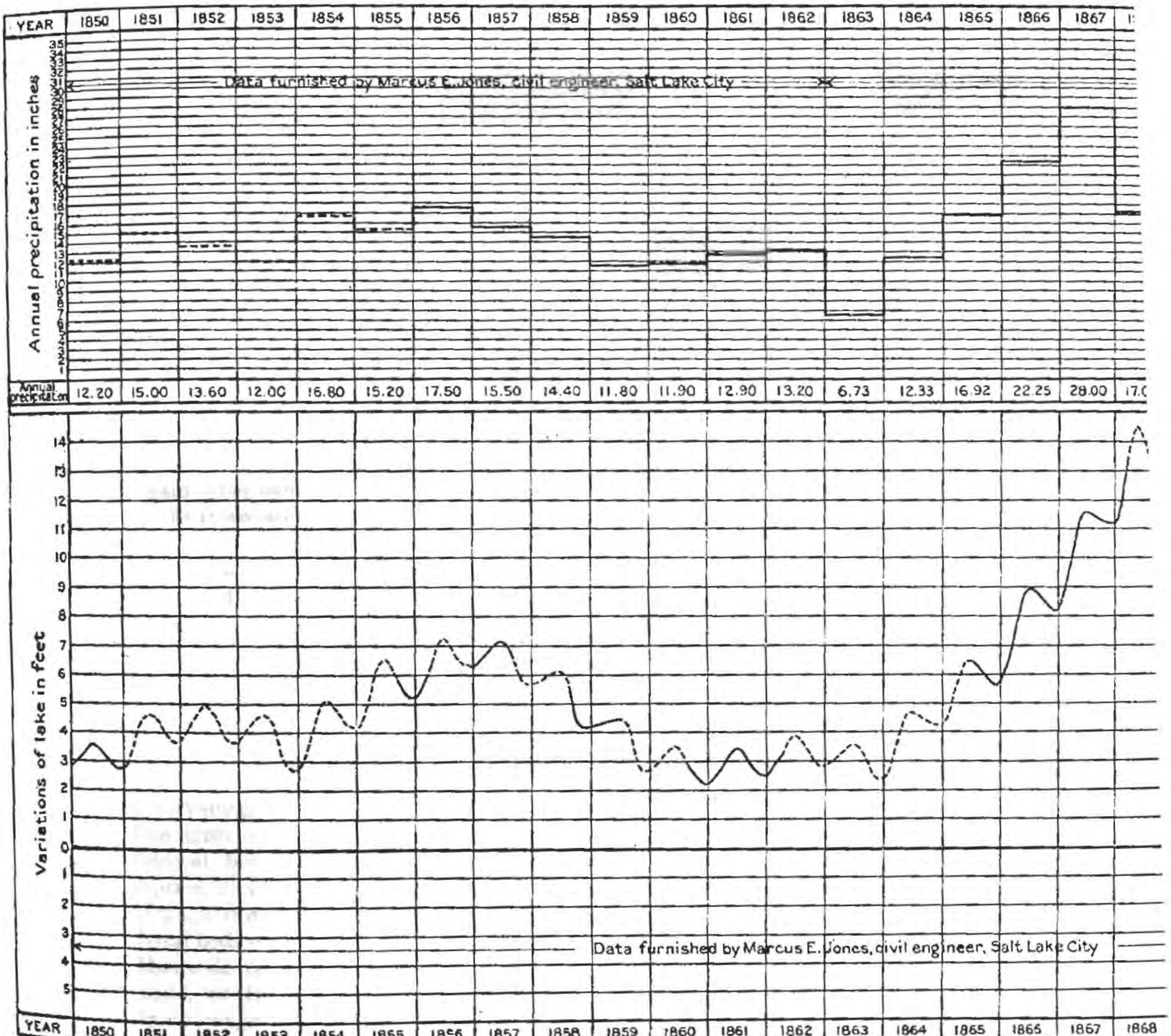
Glaciers are especially vigorous erosive agents, and where they have flowed the zone of oxidation is likely to be shallow. Such is the case, for example, in parts of Little Cottonwood and other canyons of the Wasatch Mountains. But the glaciers were confined to the heads and axial portions of the canyons, and on the intervening unglaciated ridges the veins are deeply oxidized.

The extent of oxidation has doubtless varied with the length of the seasons. In higher altitudes, like those of the Wasatch Range, the long cold winters tend to restrict the amount of waters circulating for a large part of each year and undoubtedly did so even more during the period when parts of the region were covered with ice and snow throughout the year.

The character of the rock is also of prime importance. In all parts of the State areas of soft rock have been lowered far more than neighboring areas of harder rock. Naturally ore deposits inclosed in the different types of rock will be similarly affected.

CHARACTER AND GEOLOGIC RELATIONS OF THE DEPOSITS.

Besides being subjected to the general conditions affecting the ore bodies, each type of ore deposit differs in oxidation according to its mineralogic composition and to the character of the inclosing rocks. For this reason the the alteration of each type is best discussed separately.


YEAR
1850
1851
1852
1853
1854
1855
1856
1857
1858
1859
1860
1861
1862
1863
1864
1865
1866
1867
Annual precipitation in inches
Data furnished by Marcus E. Jones, civil engineer, Salt Lake City
Annual precipitation
12.20
15.00
13.60
12.00
16.80
15.20
17.50
15.50
14.40
11.80
11.90
12.90
13.20
6.73
12.33
16.92
22.25
28.00
Variations of lake in feet
Data furnished by Marcus E. Jones, civil engineer, Salt Lake City
YEAR
1868

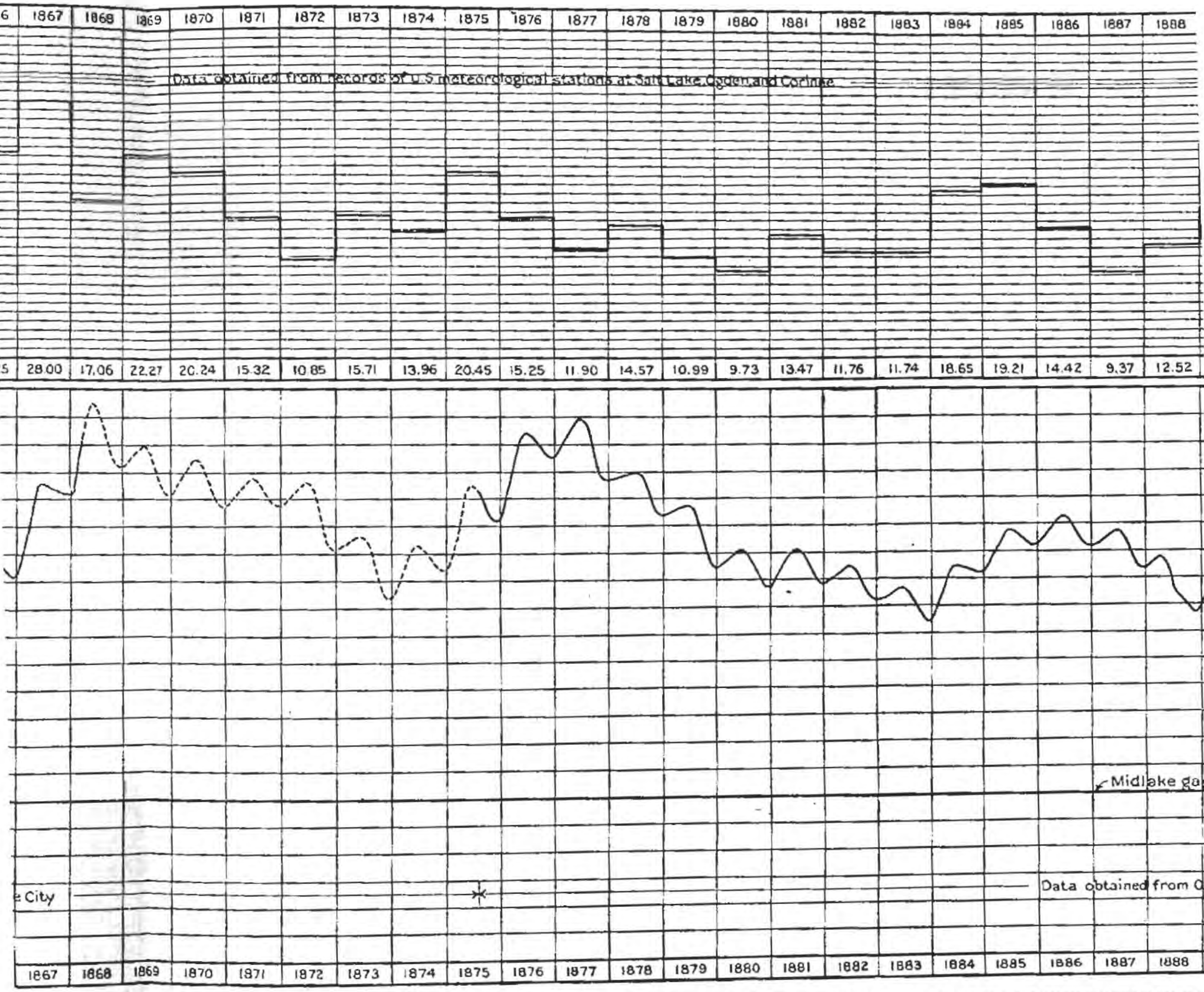
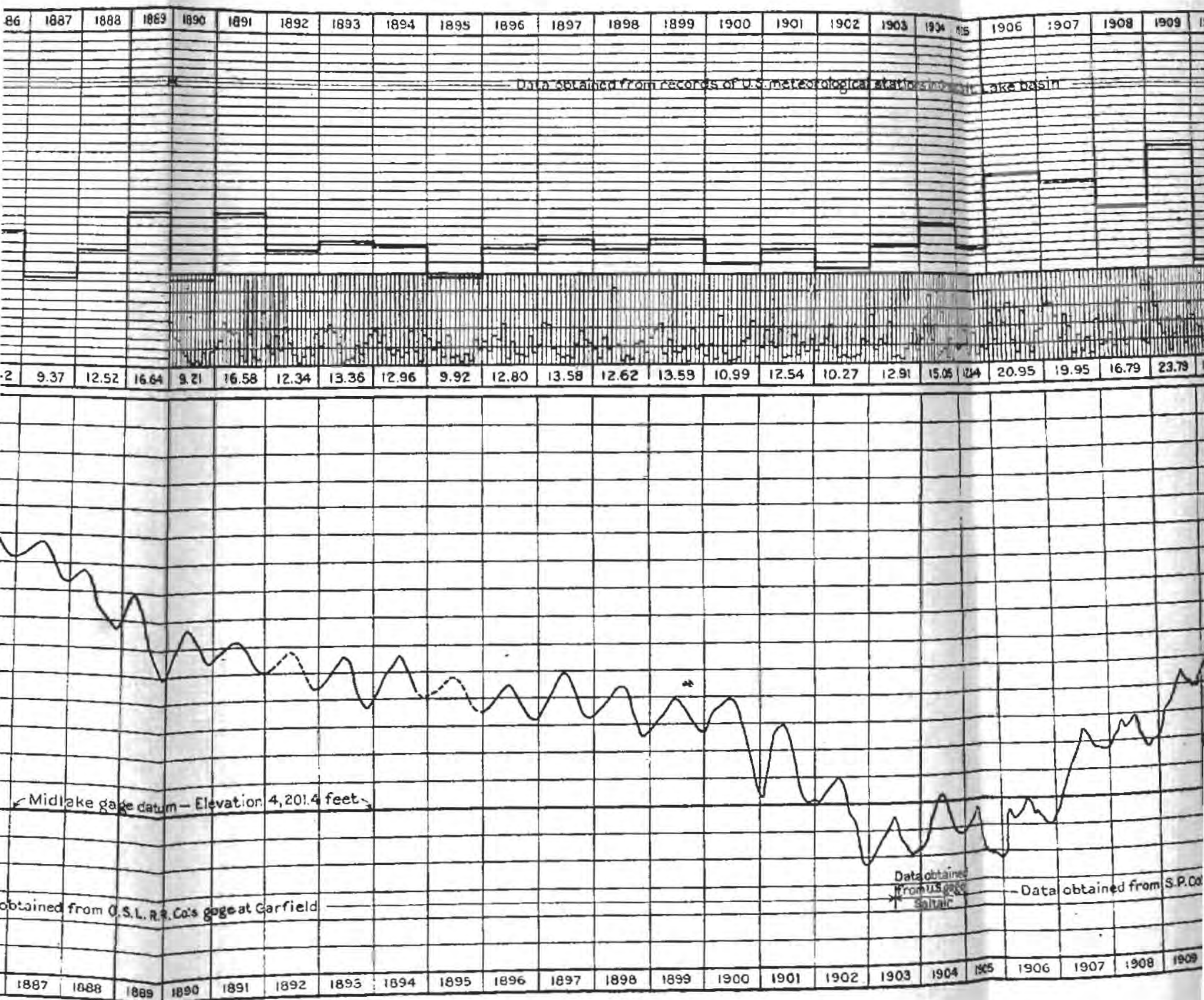
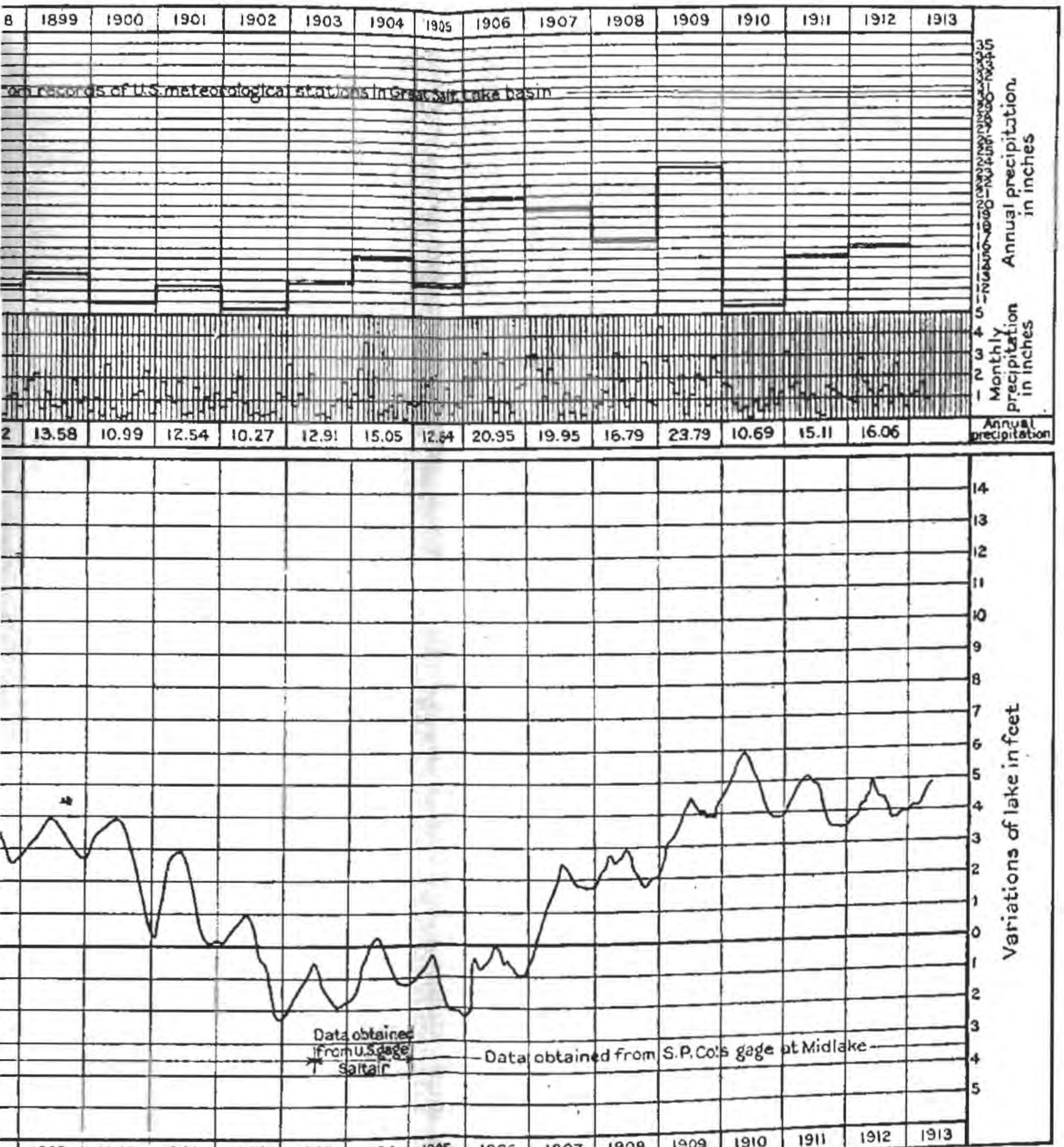


CHART SHOWING VARIATION IN LEVEL OF GREAT SALT LAKE AND THE MONTHLY AND ANNUAL PRECIPITATION IN GR

PR



TATION IN GREAT SALT LAKE BASIN.



1899 1900 1901 1902 1903 1904 1905 1906 1907 1908 1909 1910 1911 1912 1913
...om records of U.S. meteorological stations in Great Salt Lake basin
Annual precipitation in inches
Monthly precipitation in inches
13.58 10.99 12.54 10.27 12.91 15.05 12.64 20.95 19.95 16.79 23.79 10.69 15.11 16.06
Annual precipitation
Variations of lake in feet
Data obtained from U.S. gage Saltair
Data obtained from S.P. Co's gage at Midlake

ALTERATION OF THE PRINCIPAL PRIMARY METALLIC MINERALS.[1]

Ores and minerals are commonly designated as primary or secondary. By primary ores or minerals are meant those that have not been affected by the action of surface solutions, and by secondary, those that have resulted from the action of superficial agencies. Hypogene and supergene have been suggested by Ransome to designate these types. The minerals in the upper part of most of the ore bodies, or the oxidized zone, are prevailingly secondary or supergene, and those at greater depth that have not been affected by surface solutions are primary or hypogene. Between the two zones is an area in which both classes are present.

IRON MINERALS.

The principal primary iron minerals in the ore deposits are magnetite, hematite, pyrite, iron-bearing garnets, and carbonates containing iron. Less important are small amounts of pyrrhotite, several silicates containing iron, and sulphides like chalcopyrite and bornite that contain other metals combined with iron.

Magnetite is apparently very slightly acted on by surface waters. In many magnetite-bearing outcrops the mineral is perfectly fresh, and in the float from such deposits the mineral, though finely divided, is apparently not hydrated and is strongly magnetic. Likewise, in some of the bench gravels along Colorado and Green rivers finely divided magnetite that has been exposed to surface solutions for a long period is strongly magnetic and apparently little, if any, changed. Under the conditions prevailing in Utah the main effect of surface agencies on magnetite seems to be a mechanical breaking down and removal. An exception to the rule is the occurrence of martite (magnetite oxidized to hematite) grains in the basal beds of Cambrian quartzite in the Sierra Madre district.

Hematite, so far as ascertained, behaves similarly to magnetite, but its more friable character causes it to break into much finer particles, which are less readily recognized in the float and waste of the deposits.

Pyrite readily breaks down chemically when acted on by oxygen-bearing waters; and the resulting products, including ferrous and ferric sulphate and sulphuric acid, react with the other sulphides, so that the pyrite in an ore body is an important factor in its alteration. The final product of the alteration of pyrite is commonly hydrous ferric oxides (limonite), but before this product is reached the iron may have formed, not only the very soluble ferrous and ferric sulphate, but also, with other substances, the more stable basic sulphates jarosite, plumbojarosite, and beaverite, which, however, usually break down under surface conditions to less complex compounds, including hydrous iron oxides.

Iron migrates less readily, as a rule, in limestone than in siliceous rocks, probably because the ferric sulphate reacts with calcium carbonate and precipitates hydrous ferric oxide, according to the equation[2]

$$Fe_2(SO_4)_3 + 3CaCO_3 + 3H_2O = 2Fe(OH)_3 + 3CaSO_4 + 3CO_2$$

Where limonite is found in limestones at a considerable distance from its source, it is because the limestones through which it has migrated are of dense texture and siliceous or argillaceous composition and therefore are not readily susceptible to replacement.

The iron-bearing silicates, of which garnet is perhaps the most abundant in the ore deposits, break down under surface conditions, yielding hydrous iron oxide, opaline silica, and other products.

Iron-bearing carbonates are apparently not very rapidly acted on directly by oxidizing waters, though they darken on exposure, suggesting oxidation of the iron. They readily break down under the action of oxidation products of pyrite, notably of sulphuric acid, and finally form hydrous iron oxides.

MANGANESE MINERALS.

Primary manganese minerals in the ore deposits of the State are relatively few and are of relatively slight importance in individual deposits except in the "sandstone manganese deposits" of the Plateau region. Manganese occurs in much of the vein carbonate and is probably present in the sulphides, though it has not been recognized in them. In the West Tintic district the manganese ores have apparently resulted from the alteration of rhodonite.

[1] For detailed discussion of the chemistry of the alteration see Emmons, W. H., The enrichment of ore deposits: U. S. Geol. Survey Bull. 625, 1917, also textbooks and special articles.

[2] Knopf, Adolph, Mineral resources of the Inyo and White mountains, Cal.: U. S. Geol. Survey Bull. 540, p. 106, 1914.

In the secondary ores small amounts of manganese oxide and hydrous oxide are present in nearly all the deposits and in a few are abundant. Manganese has recently been mined in the East Tintic district, just south of Homansville Canyon. In 1917 and 1918 shipments were made from the North Tintic and West Tintic districts. It has been shipped from the Little Cottonwood district and is present in the Marysvale district, near Modena, and at other localities.

COPPER MINERALS.

The more important primary copper minerals are chalcopyrite, enargite, and tetrahedrite, and numerous others have copper as a constituent. (See Pl. XXIII.)

Chalcopyrite, under the influence of oxidizing waters, especially when associated with pyrite, as it almost invariably is in the ore deposits, readily alters to iron and copper sulphates. The iron, like that in pyrite, is in part eventually converted into hydrous ferric oxide. If calcite is present, the copper sulphate resulting from the first alteration reacts with it to form copper carbonate or with silica to form copper silicates; the relatively stable basic sulphates may form under some conditions, though, so far as observed, brochantite commonly forms from the alteration of chalcocite or covellite. In the absence of calcite the copper-bearing solutions and other products of the alteration of chalcopyrite and pyrite pass out of the zone in which they formed. If they come in contact with sulphides below the zone in which oxygen is available, the copper is precipitated as the secondary sulphides chalcocite, covellite, or bornite, or, more rarely, as secondary chalcopyrite. The secondary sulphides in turn come into the zone of oxidation and on alteration produce native copper, the oxides cuprite and melaconite, the carbonates and silicates, and the basic sulphate brochantite; or they may again form soluble sulphate and be carried away in solution to be again precipitated by other sulphide.

The alteration of enargite results in a series of copper-arsenic compounds and the more common copper carbonates and silicates. Scorodite and pharmacosiderite are common alteration products of arsenic compounds and are doubtless formed in the oxidation of enargite associated with iron minerals as well as in the alteration of arsenopyrite.

The copper of tetrahedrite on oxidation usually forms the common carbonates and silicates, and the antimony, if lead is present, commonly unites with it to form bindheimite or closely allied compounds.

LEAD MINERALS.

Galena is by far the most important primary lead mineral in the ore deposits of the State, jamesonite or some closely allied mineral is present in some of the deposits, and other lead minerals occur in small amount.

The alteration of galena as a rule first forms the sulphate, anglesite, which in deposits in limestone usually alters to the carbonate, cerusite. Frequently, however, more complex sulphates, such as plumbojarosite (see fig. 33, p. 210) and beaverite, are formed, which eventually break down and form simpler combinations, the final oxidation mineral of the lead most commonly being cerusite. Jamesonite commonly alters to antimony-lead compounds, probably most commonly to bindheimite.

ZINC MINERALS.

Sphalerite is the only primary zinc mineral of importance thus far recognized in the ore deposits of the State. When acted on by sulphuric acid or by certain sulphates it alters to the sulphate, which is very soluble and is readily carried in solution. On coming in contact with limestone the zinc of the sulphate is precipitated as smithsonite, hydrozincite, or under certain conditions in the presence of silica as the hydrous silicate, calamine, or, rarely, as the anhydrous silicate, willemite. Other minerals are formed to a slight extent, as aurichalcite and zinc-bearing clay. If the acid sulphate solutions pass below the zone of free oxygen into primary sulphides, the acidity is reduced and the zinc may be precipitated as sulphide; in some places as the hexagonal sulphide, wurtzite. Smithsonite, hydrozincite, calamine, and wurtzite are the principal secondary minerals, though others are present in small amounts. (See Pls. XXIII, XXIV, and fig. 33.)

ARSENIC MINERALS.

Several primary arsenic minerals are present in the ore deposits. On oxidation these yield realgar, orpiment, scorodite, pharmacosiderite,

A. OXIDIZED COPPER ORE FROM THE COPPER MOUNTAIN MINE, LUCIN DISTRICT.

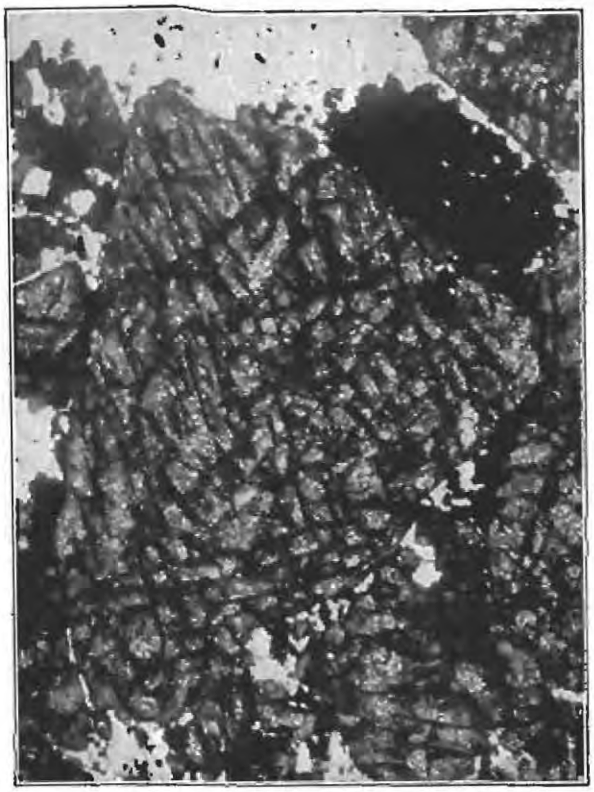
Large, dark areas, cuprite; dark bands surrounding cuprite, melaconite; light band outside of melaconite and small spots in the light areas, malachite; light areas, aluminum silicate containing variable amounts of copper.

B. SMITHSONITE PSEUDOMORPHS AFTER CALCITE, FROM THE SEVENTH LEVEL OF THE HORN SILVER MINE.

Natural size.

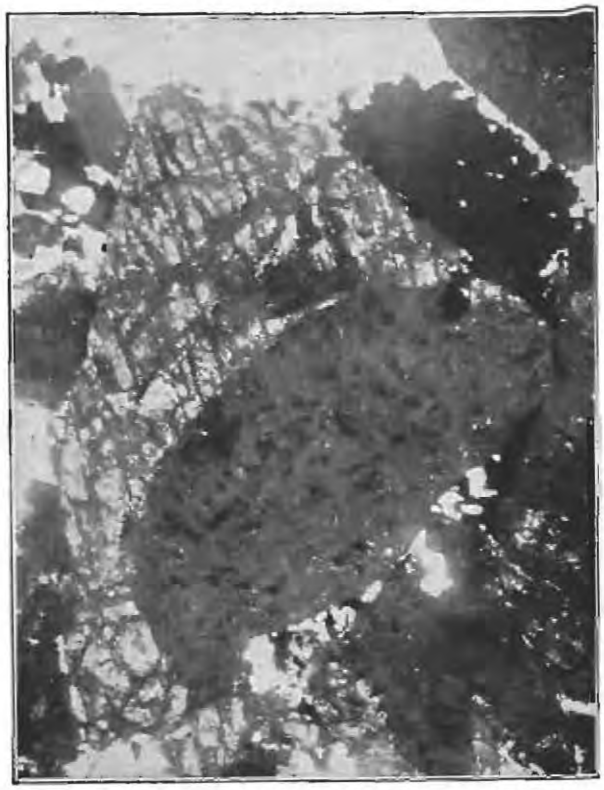
C. COVELLITE REPLACING ZINC SULPHIDE.

Zinc sulphide in the center surrounded by zones of covellite containing considerable unreplaced zinc sulphide, from the Horn Silver mine. Collected by D. P. Rolfing.



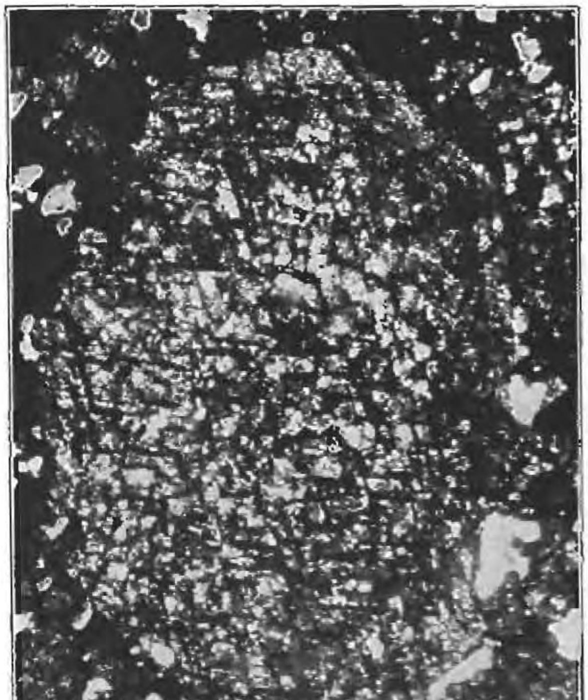
A. PHOTOMICROGRAPH OF SPECIMEN OF ZINC SULPHIDES FROM THE HORN SILVER MINE.

Dark-gray areas, zinc sulphides, sphalerite, and wurtzite. Ordinary light. Enlarged 43 diameters.



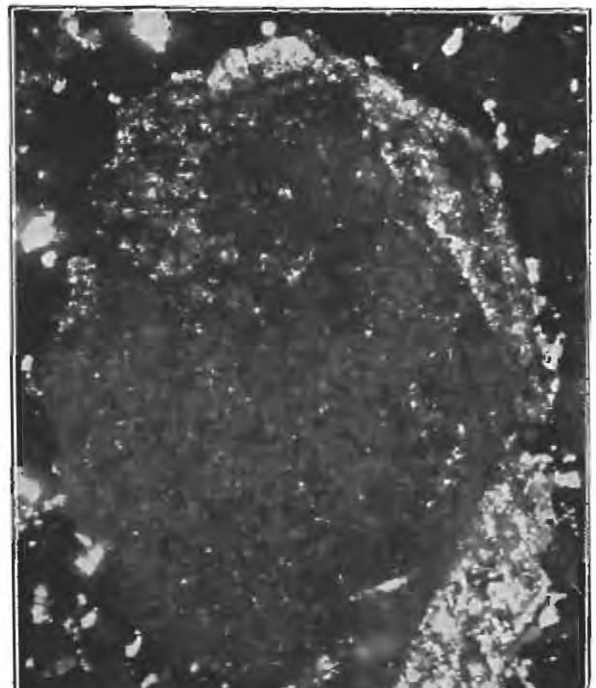
B. PHOTOMICROGRAPH OF SPECIMEN SHOWN IN *A*, WITH CROSSED NICOLS.

Dark areas, sphalerite; light-gray areas, wurtzite. Enlarged 43 diameters.



C. PHOTOMICROGRAPH OF CRYSTAL OF ZINC SULPHIDE IN ORDINARY LIGHT.

Enlarged 43 diameters.



D. PHOTOMICROGRAPH OF CRYSTAL SHOWN IN *C*, WITH CROSSED NICOLS.

Light areas, wurtzite surrounding a center of sphalerite.

and compounds of arsenic with other metals, notably copper.

ANTIMONY MINERALS.

Antimony is present in the primary ores as stibnite and in combination with other metals, notably as tetrahedrite and jamesonite. The alteration products of stibnite are valentinite, kermesite, or closely allied minerals. Bindheimite is a common alteration product of ores containing both lead and antimony.

SILVER MINERALS.

The silver of the primary ores occurs in argentite and in several arsenic and antimony compounds, and to a slight extent in selenides and tellurides. By far the most abundant secondary mineral is cerargyrite, though some native silver and some secondary sulphide and antimony and arsenic compounds are present.

GOLD MINERALS.

The gold of the primary ores occurs as native metal in selenium and tellurium compounds, and in sulphides in an undetermined form. The native metal is the only secondary product recognized.

URANIUM AND VANADIUM MINERALS.

Uranium and vanadium deposits in the Plateau region have not yet been sufficiently developed to determine positively which minerals are primary and which secondary. Some of the minerals that have formed as an efflorescence are certainly secondary, as pintadoite, uvanite, and certain undetermined uranium sulphates. Whether some of the more abundant minerals, as carnotite and hewettite, are primary or secondary is doubtful.

ALTERATION OF DEPOSITS IN SANDSTONE.

Most of the ore deposits in sandstone (see p. 152), as seen in natural exposures and in shallow development works, are thoroughly oxidized, though sulphides have been reached in a few such deposits.

SILVER DEPOSITS.

In the Silver Reef district cerargyrite and native silver lie near the surface, but at greater depth give place to argentite, which is believed to be the original silver mineral. Lindgren[1] has suggested that the argentite is secondary and that it resulted from a concentration from argentiferous chalcocite. Some secondary argentite may have been deposited, but the writer has failed to find evidence that it is important.

The copper minerals of the Silver Reef district are mainly azurite, malachite, and chalcocite. Whether or not the chalcocite is original has not been determined. Secondary iron minerals are rather abundant, and were probably derived in part at least from the alteration of iron or copper-iron sulphides. The chalcocite may have formed by replacement of such iron-bearing minerals as did chalcocite in some of the "sandstone" copper deposits.

So far as determined alteration has neither pronouncedly enriched or impoverished the silver deposits in the Silver Reef district. In the main the change has been to minerals that are relatively stable under surface conditions and migration has been slight.

COPPER DEPOSITS.

The few instances where sulphides have been observed in "sandstone" deposits in which copper is the principal valuable constituent affords abundant evidence of replacement of chalcopyrite and pyrite by covellite and chalcocite. Such replacements are especially well shown in the Big Indian deposits (Pl. XLIX) and in the Blue Dike deposits in White Canyon, where the structure of the wood is preserved through replacement by chalcopyrite and subsequent replacement of the chalcopyrite by chalcocite and covellite (Pl. XIV, p. 152). The rather abundant secondary iron minerals associated with the oxidized copper ores also suggest that iron-bearing sulphide occurred in the original ores of the deposits where it has not been found. Chalcocite and covellite have in turn been altered to the carbonates malachite and azurite, which are the prevailing copper minerals in most of the deposits to the depth to which they have been developed.

Most copper deposits of this character observed by the writer lack a marked zone of leaching, and it is not certain that the copper sulphides are due to the surface solutions.

URANIUM AND VANADIUM DEPOSITS.

Too little is known of the original character of the uranium and vanadium deposits to make discussion of their alteration at this time profitable. An undetermined uranium sulphate that

[1] Lindgren, Waldemar, Mineral deposits, p. 374, 1913.

is associated with chalcopyrite, chalcocite, and covellite in the Blue Dike prospect in White Canyon may have been derived from the oxidation of the sulphides, but in the material at hand it was not possible to free the sulphides from the uranium sulphate so as to test them for the presence of uranium.

DEPOSITS IN INTRUSIVE ROCKS.

PEGMATITIC GOLD QUARTZ VEINS.

The pegmatitic gold quartz veins (see p. 159) are open and readily accessible to the agents of surface alteration, and the presence of abundant hydrous oxide of iron indicates that iron minerals have been oxidized. Developments below the oxidized zone had been too meager to determine the change in metal content due to oxidation, but the gold content seems to be as large near the surface as at any point at greater depth, as if leaching of gold had not been important. However (see p. 486), the richest ore shoots in the Queen of Sheba mine occur in fractures younger than the veins and are most readily accounted for by concentration of the gold by surface agencies.

COPPER DEPOSITS IN INTRUSIVE ROCKS.

The oxidized products of the different types of copper deposits (see p. 160) in intrusive rocks show many similarities and some marked differences, due primarily to differences in the original mineral composition.

QUARTZ-TOURMALINE COPPER DEPOSITS.

The primary ores of the quartz-tourmaline copper deposits, in both the San Francisco and Clifton districts, contain important amounts of calcite and of calcium-magnesium-iron-manganese carbonate. This has resulted in the formation of abundant copper carbonate in the zone of oxidation and in very little sulphide enrichment. The Cactus mine, for instance, contains practically no enriched sulphide ore. Development in veins of this type in the Clifton district has not extended below the zone of carbonates, but the abundance of carbonates in the surface zone indicates that sulphide enrichment has not been great.

QUARTZ COPPER DEPOSITS.

The quartz copper veins and associated replacement deposits of the Bingham and Beaver Lake districts, in which carbonates are lacking in the primary ores or are present only in small amounts, afford alteration products of very different character. In the upper part the sulphides have been entirely oxidized and practically all of the copper and much of the iron removed. The iron not removed is present as limonite or similar hydrous ferric oxides. The gold content shows no decrease, and doubtless the gold has been eroded with the silicates and has contributed to the placers, as those of Bingham Canyon. At greater depth the copper content in the form of carbonates and possibly in part as basic sulphate increases, and a little iron is apparently present as basic sulphate, though in what mineral combination has not been determined. At still greater depth sulphides are mixed with carbonates, oxides, and sulphates, and these give place to the zone of secondary sulphide, which consists of pyrite, chalcopyrite, and some bornite, partly replaced by chalcocite and covellite.

In the Bingham district the amount of copper in the form of carbonates and other oxidized minerals in the material above the sulphide ores varies considerably.[1] (See also p. 359.) In the portions of the deposits highest above the canyon bottom very little copper is present above the sulphides, but near the canyon bottom the oxidized ores immediately above the sulphides contain nearly or quite as much copper as the sulphide ores.

The relative amount of the secondary sulphide minerals in the enriched sulphide zone also varies. Beeson states that in the deposits highest above the canyon bottom covellite predominates over chalcocite and that near the canyon bottom the reverse is true. This difference he attributes to varying conditions of acidity and the content of ferrous sulphate.

At greater depth the amount of the secondary sulphides gradually decreases till the zone of primary sulphides is reached below the influence of oxidizing solutions. The transition from the zone of carbonates and sulphates to that of sulphides is rather abrupt, taking place within a few feet and in many places within a few inches. In general, however, the copper content shows no such notable change, and where the ores are high grade they are of about

[1] Beeson, J. J., The disseminated copper ores of Bingham Canyon, Utah: Am. Inst. Min. Eng. Bull. 107, pp. 2191-2236, 1915.

the same value above and below the transition. Where they are low grade, however, as in the Bingham deposits, the difficulties of treatment have caused the ores from above this line to be stored to await metallurgic development. The greatest concentration of copper apparently lies near the line separating secondary sulphides and the more highly oxidized carbonate oxide and sulphate. Above this line there is a decrease in copper due to downward leaching and below it there is a progressive change toward the leaner primary sulphides. The change from the secondary sulphides to primary ore is gradual, no sharp line separating ore from material too low in metals to be profitably treated.

In the Utah Copper Co.'s ore body (see Pl. XXXV, p. 358) the depth at which the sulphides have been changed to carbonates and oxides varies with the elevation above the canyon bottom. The thickness of the oxidized zone on the higher elevations is more than twice what it is under the bottom of the canyon.

QUARTZ SILVER-LEAD VEINS.

The oxidation of the silver-lead veins in the intrusive rocks (see p. 162) is in general similar to that of the silver-lead veins and replacement deposits in the sedimentary rocks and need not be described in detail. The zinc content of the deposits, however, has been markedly reduced. Whether the zinc has been in part precipitated in the sulphide zone, as in the Horn Silver mine (see p. 213), or has been dissipated by the circulating waters has not been determined.

IRON VEINS.

Alteration of the magnetite-hematite iron deposits in the intrusive rocks is similar to that of the replacement deposits. (See p. 168.) Certain iron deposits in the Antelope Range near Marysvale and in the Dragon mine in the Tintic district consist of hydrous iron oxide and are attributed principally to the concentration of the oxidized products of disseminated pyrite in altered igneous rocks. (See p. 163.)

CONTACT DEPOSITS.

The physical and chemical character of the contact deposits is not favorable to rapid oxidation, and their alteration by surface solutions is usually relatively superficial. Physically the deposits are characteristically dense and relatively impervious to solutions. Mineralogically they are composed largely of relatively inert oxides and silicates and of sulphides in too small amount to cause the rock to break down rapidly.

IRON DEPOSITS.

Contact deposits chiefly valuable for their iron content are present in the Iron Springs and Bull Valley districts (p. 168) but show relatively slight surface alteration. Leith and Harder note that hematite appears to be more abundant below the surface and that silica is distinctly so. The sulphur content also appears to be less near the surface. The changes due to oxidation are favorable to the quality of the ore.

COPPER DEPOSITS.

The surface alteration of the contact copper deposits has been relatively shallow. Some concentration of the copper has occurred producing "bunches" of relatively high grade enriched sulphide and carbonate and oxide ores.

For a short distance below the surface the deposits have been impoverished in copper. At greater depth the copper content increases but is commonly concentrated along lines of easiest passage of solutions. At greater depth the primary ores are reached. In the oxidized zone some "bunches" of rather high-grade ore have been extracted, some of them probably at a profit. In the primary zone, where silicates are the prevailing gangue, most of the material is too low grade for profitable mining. In the deposits in which the gangue is largely iron oxides there has been a similar enrichment, though usually less localized and consequently producing ore with a lower copper content. With favorable mining and transportation facilities, however, even the primary ore with an iron oxide gangue can be profitably mined, owing to the value of the iron as a flux.

GOLD DEPOSITS.

The contact gold deposits of the Clifton district consist mainly of silicates and have undergone relatively slight surface alteration. Some of the richest specimens seen, however, were distinctly oxidized; the gold in them occurs along fissures and is associated in places with copper sulphide. This relation suggests that there has been some movement of the gold during oxidation.

REPLACEMENT DEPOSITS IN AND ADJACENT TO FISSURES IN SEDIMENTARY ROCK.

DEPTH OF OXIDATION.

Replacement deposits associated with fissures in the sedimentary rocks have commonly been extensively oxidized, many of the fissures being sufficiently open to permit rather free circulation of waters. The minerals forming the deposits yield readily to oxidizing solutions. The relatively open character of the fissures, especially in limestones, as compared with those in the intrusive rocks, permits deep circulation of the oxidizing waters. These factors have produced a very deep zone of oxidation in many of the deposits.

The results of alteration vary greatly with the metal content of the deposits.

COPPER DEPOSITS.

The alteration of the copper deposits is in general similar to that of those in the intrusive rocks and, as in the intrusive rocks, varies considerably with the character and mineral composition of individual deposits. The primary ores of the larger deposits consist principally of pyrite but contain chalcopyrite and other metallic minerals. Gold and silver are present in variable but usually in small amount. Quartz is the prevailing gangue mineral and in many places has replaced the limestones surrounding the main sulphide bodies. Where these replacement bodies are oxidized the copper has migrated downward in notable amounts and has formed an important zone of sulphide enrichment, as in the Highland Boy and other deposits of the Bingham district. The gold, in part at least, has remained in the leached portion, and some of the gossans in the Bingham district have been treated to recover it. The secondary sulphides, however, are richer in gold and silver than the primary deposits, indicating a concentration.

In many smaller deposits, where the replacement of the limestone is less complete and calcium carbonate is an important gangue mineral, the sulphide enrichment is far less important. In these the copper sulphate formed by the oxidation of the original sulphides has reacted with the calcite of the gangue and has formed the relatively stable copper carbonates. Some secondary sulphide was usually formed but is of relatively slight importance.

The oxidation of a secondary sulphide zone that has been so enriched that it consists largely of copper sulphides results in the formation of native copper, cuprite, and melaconite or tenorite, and very commonly of silicates and carbonates. Such an alteration seems to have produced the rich oxidized ores of the Copper Mountain mine in the Lucin district (see Pl. XXIII), though sulphides were not observed in the mine at the time of the writer's visit. The absorption of copper by amorphous siliceous and aluminous material has formed ore ranging from rather high grade to that containing but little copper.

In the deposits containing abundant arsenic, as the Tintic mines and the Gold Hill mine of the Clifton district, a series of copper-arsenic oxidation minerals form an important part of the ore.

LEAD-SILVER DEPOSITS.

The primary ore of deposits in which lead and silver are the most important metallic constituents is composed chiefly of pyrite and galena with variable amounts of sphalerite, tetrahedrite, enargite, chalcopyrite, and other minerals. In most deposits the mineral combination in which the silver is present has not been determined. It is closely associated with the sulphides and allied minerals and probably occurs as silver sulphide and combined with arsenic and antimony, intergrown with lead, zinc, and copper minerals.

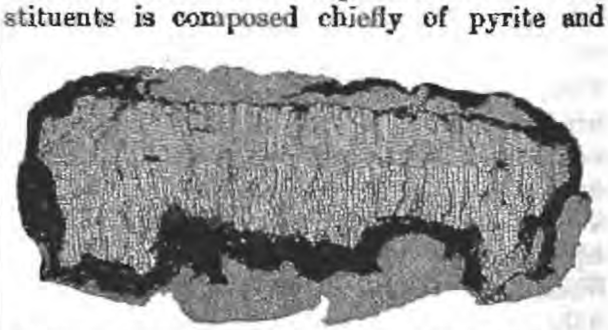


FIGURE 33.—Diagram showing the relation of galena and its oxidation products. Drawn from specimen from Alta Consolidated mine, Little Cottonwood district. Central area, galena; dark band surrounding galena and penetrating it along cleavages, anglesite with some cerusite; outer band, basic ferric sulphate, possibly beaverite.

When acted on by oxidizing solutions, the galena first alters to the sulphate, anglesite. The anglesite in the presence of calcium and magnesium carbonates changes to the lead carbonate, cerusite, or combines with ferric sulphate to form plumbojarosite or other complex basic ferric sulphates. (See fig. 33.) If antimony is present, lead-antimony minerals may result.

Other oxidized lead minerals are present in the deposits in small amounts. All the lead minerals resulting from oxidation are relatively insoluble, and lead migration is consequently small.

The mineral combinations of the silver in the oxidized ores are not all known. Many ores contain it in large part as the chloride, cerargyrite; but others (as some in the Lion Hill area) consist of earthy yellow or greenish material, commonly designated "chlorides" or "bromide," which is too finely divided for determination even under the microscope. It contains ferric iron and sulphate radicle and in appearance suggests some of the complex basic sulphates, but it has not been determined that the silver is present in such a combination. Some yellow "chlorides" consist essentially of the hydrous lead antimonate bindheimite; and some green ores rich in silver owe their color to copper minerals.

The oxidized ores are commonly quite as rich in silver as the unoxidized, indicating that there has been little migration of the silver. In some mines silver has been concentrated in oxidized ore. Salt is abundant in the desert valleys, and doubtless there is sufficient salt in the waters entering the deposits to precipitate all the silver from the sulphate solutions as chloride. Even in the Park City district, relatively remote from the desert valleys and with moderately high precipitation, the mine waters contain rather abundant chlorine. Probably there has been some migration of the silver, but it does not appear to have been important. Zinc, however, has been largely removed from deposits containing sphalerite; and iron has been removed from at least some ores and deposited as ferruginous zinc carbonate, as in the Tintic district, though in large part it has been changed to the stable hydrous ferric oxide. In general, therefore, removal of other constituents has caused some enrichment in lead and silver. Moreover, the treatment of the oxidized ore is commonly cheaper than that of the primary ore.

SILVER DEPOSITS.

Deposits whose content of lead, zinc, and copper is relatively low, and which may therefore be regarded as silver deposits, occur in the Lion Hill region, in parts of the Ontario vein system of the Park City district, and elsewhere. The alteration of the ores does not differ in character from that of the lead-silver ores.

ZINC-LEAD-SILVER DEPOSITS.

Zinc is present in the primary ores of most of the replacement deposits, and in many of them is sufficiently abundant to be profitably recovered. Thus for several years zinc has been recovered from the sulphide ores of the Park City and Bingham districts.

The oxidation of this type of ore differs in no wise from that of the lead-silver ores, the only difference in the ores themselves being the relative amounts of the several mineral constituents. The oxidation of the sulphides (p. 206) produced sulphates of the different metals. The lead sulphide, which altered to sulphate and eventually to carbonate, both relatively insoluble, migrated little if any. The silver sulphate in large part probably reacted with chlorides in the waters, producing the slightly soluble silver chloride, and it, too, migrated little. Iron and zinc sulphates, on the other hand, are easily soluble and migrate readily, though in the presence of abundant oxygen the iron sulphate may change to the hydrous iron oxide, which has little tendency to migrate. The sulphate solutions pass downward under the influence of gravity and eventually pass out of the original ore body, usually into the footwall along structural breaks or bedding planes. On coming in contact with limestone the zinc is precipitated as carbonate or basic carbonate, the ferrous iron is precipitated as carbonate, and any ferric iron present is probably precipitated as hydrous ferric oxide.[1] The ferrous iron and zinc may be precipitated together, as in the Tintic district, as the iron-zinc carbonate monheimite. The relative proportion of the metals in the mineral is probably dependent on their relative concentration in the solution. The carbonate thus formed may subsequently alter to limonite, calamine, hydrozincite, aurichalcite, and probably other minerals.

If the solutions in their downward journey do not encounter limestone but traverse quartzite or other siliceous materials the metals show little tendency to precipitate and are probably either carried away in solution or are so dispersed before precipitation that

[1] Knopf, Adolph, Mineral resources of the Inyo and White mountains, Cal.: U. S. Geol. Survey Bull. 540, p. 106, 1914.

they do not form deposits of economic importance. Under favorable conditions the solutions might travel for some distance through siliceous beds without being dispersed and on coming in contact with limestone might form commercial deposits.

The most favorable conditions, then, for the formation of oxidized zinc ores are where

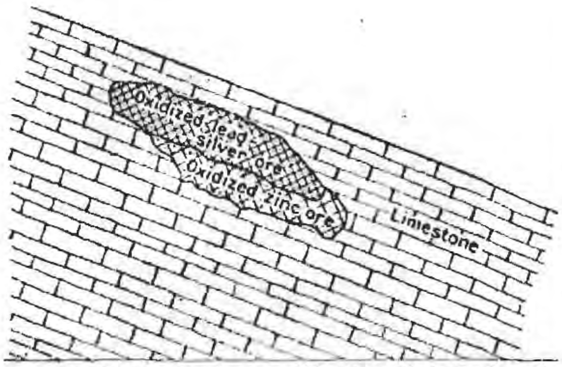


FIGURE 34.—Diagram showing a condition favorable to the formation of oxidized zinc deposits.

the primary ores are underlain by limestones or dolomites which are free from insoluble impurities, and into which the downward-moving solutions from the oxidizing sulphides may pass. (See fig. 34.) The purity of the limestone probably has an important effect on the value of the deposits, both because any siliceous impurities would doubtless remain in the carbonate ore and thus reduce its value, and because the precipitating effect of impure limestones is probably much less than that of the relatively pure limestone, as it apparently is in primary deposits (p. 174).

Under the most favorable conditions important secondary zinc deposits may form from primary deposits containing only a small percentage of zinc. Thus Knopf[1] has shown that in the Cerro Gordo mine large bodies of oxidized zinc ores have been formed by the alteration of sulphide bodies containing only 1 to 2 per cent of sphalerite.

In Utah considerable zinc is present in the primary deposits of many districts but important secondary zinc deposits have been developed in but few, the principal ones being the North Tintic, Tintic, Ophir (Dry Canyon), Promontory, Big Cottonwood, and Star districts. The Park City and Bingham districts contain primary deposits sufficiently rich in zinc to be mined, but so far as known the oxidation of these deposits has not formed extensive carbonate deposits. This apparent lack may be due to the fact that in the Park City districts some of the principal deposits lie but a short distance above the great Weber quartzite, and that in the Bingham district most of them occur in lenses of limestone in the Bingham quartzite. In both localities solutions passing downward from the deposits would enter the siliceous rocks and would probably be dispersed. (See fig. 35.) In the Tintic, Ophir, and Star districts, on the other hand, the developed zinc deposits are so situated that the solutions from the oxidizing sulphide bodies enter limestone and precipitate their zinc close to the primary ore bodies.

Some deposits in which oxidized zinc ores have not yet been found in large amount seem favorable for their formation, as, for instance, some of the deposits in the limestone in the Little Cottonwood district. Oxidized zinc minerals are known to occur in that district, but as yet no large deposits have been developed.

GOLD DEPOSITS.

Important gold deposits of the replacement fissure type in the sedimentary rocks occur in but few districts. In the Mercur district,

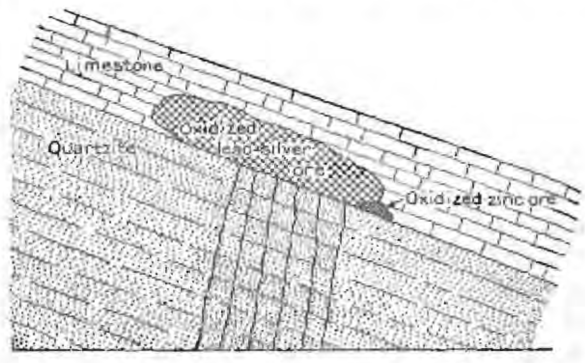


FIGURE 35.—Diagram showing a condition unfavorable to the formation of oxidized zinc deposits.

however, deposits of this type have yielded a large output, and in other districts, notably in the Deertrail mine in the Marysvale district, ores have been developed.

Whether or not surface alteration has caused important changes in the gold content of the ore is difficult of proof. In the Mercur district the gold is so finely divided that neither free gold nor gold minerals have ever been recognized, and consequently it has not been possible to determine the relation of the gold to other

[1] Knopf, Adolph, op. cit., p. 107.

constituents of the ore. On the basis of the gold content the evidence seems conflicting. The ore contains quite as much gold at or very near the outcrop of the ore bodies as at any greater depth, indicating that there has been no important leaching from the surface zone with reprecipitation at greater depth. On the other hand, as the depth below the outcrop of the deposit increases there is in general a decrease in the gold content, though there is no notable change in the character of the material after the sulphide zone is reached. This decrease in goid content downward may be interpreted as meaning that there has been enrichment near the surface due to oxidation processes, or that more metal was originally deposited at higher horizons. From the evidence now available no definite conclusion seems justified.

DEPOSITS IN VOLCANIC ROCKS.

SILVER-LEAD-ZINC-COPPER DEPOSITS.

Deposits in the volcanic rocks containing large amounts of silver, lead, zinc, and copper are confined to the San Francisco district and the Tushar Range, and important production is confined to the San Francisco district alone.

The Horn Silver mine, which presents an excellent example of the changes due to oxidation, is the only deposit of the type in the State that has been studied in detail. The deposit is a replacement of brecciated volcanic rock, which forms the hanging wall of a fault fissure whose footwall consists of limestone. Its geologic relations are such that the oxidizing solutions have passed to the ores through the volcanic rocks rather than through the limestone, and, except along fractures, have apparently penetrated but a short distance into the limestone. The unusual phenomenon is thus presented of an ore body that has formed in siliceous rock rather than in adjoining limestone.

The primary ore consists of sulphides of iron, lead, zinc, and copper and some antimony and arsenic minerals and silver in an undetermined mineral combination. The gangue is mainly quartz and barite and altered volcanic rock. In alteration the sulphides are first oxidized to sulphates. As there is little or no carbonate in the gangue and apparently little in the solutions, alteration from sulphates to carbonates has been slight. Most of the lead of the oxidized ores occurs as anglesite, and much of the copper occurs as the basic sulphate, brochantite; the more complex sulphates plumbojarosite, beaverite, and linarite are also present. Chlorine is abundant in the waters and has combined with the silver to form cerargyrite, the principal silver mineral in the oxidized ores. The lead sulphate and the silver chloride are both relatively insoluble and neither has migrated much. The soluble iron, zinc, and copper sulphates have, on the other hand, been carried downward in large part. Some of the copper, as already noted, forms the relatively insoluble basic sulphate, which, however, breaks down under near-surface conditions. Some of the iron is oxidized to hydrous ferric oxides.

A large part of the iron sulphate and probably much of the zinc sulphate has apparently been carried away in solution and dispersed. Part of the zinc, however, was reprecipitated in the sulphide zone as the hexagonal sulphide wurtzite, usually forming in zones of brecciated ore and frequently surrounding grains of sphalerite. (See Pl. XVII.) The cause of precipitation is believed to be essentially as follows:[1] The solutions passing from the oxidizing zone contain, in addition to zinc sulphate, sulphuric acid and hydrogen sulphide. As the solutions pass to deeper levels their acidity is reduced by reaction with alkaline solutions from the adjacent rocks or with the alkaline silicates of the gangue minerals. This reduction of acidity causes the precipitation of a part of the zinc as wurtzite. The precipitation apparently takes place slowly and the zone of sulphide enrichment of zinc is deep.

When the solutions have passed below the zone of oxidizing conditions their copper content reacts with the zinc, iron, and lead sulphides, forming covellite and chalcocite, principally covellite. This reaction takes place much more rapidly than the reduction of the zinc, and consequently the zone of enriched copper sulphides is relatively shallow and the copper itself is probably much more completely precipitated.

Owing to this difference in precipitation and to the fact that the secondary copper sulphide

[1] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, p. 154, 1913.

is largely formed by the replacement of the zinc sulphide, the secondary copper ores generally overlie the zinc ores, though of course with many irregularities. The general vertical arrangement of the ores (see fig. 36) begins with oxidized lead-silver ores at the top, followed in turn by oxidized lead-copper ores,

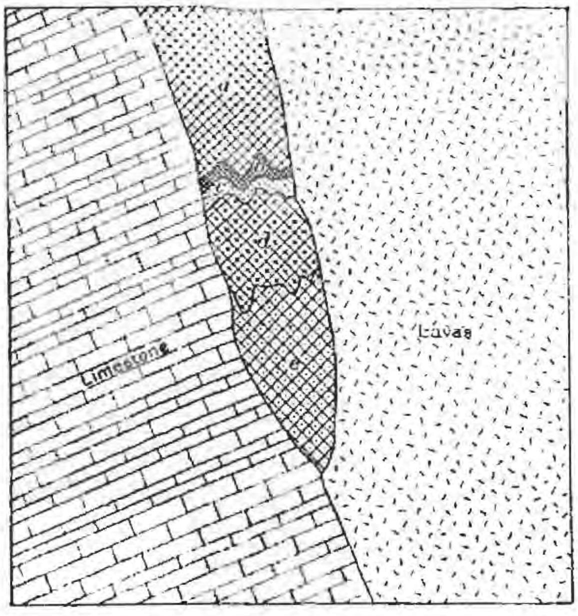


FIGURE 36.—Diagram showing the sequence of the different zones in the Horn Silver mine. *a*, Oxidized lead-silver ore; *b*, oxidized copper ore; *c*, enriched sulphide copper ores; *d*, enriched sulphide zinc ores; *e*, primary mixed sulphides.

enriched sulphide copper ores, enriched sulphide zinc ores, and primary mixed sulphide ores.

GOLD-SILVER DEPOSITS.

Gold-silver deposits in the volcanic rocks have been productive in the State Line-Gold Springs districts and in the Tushar Range. At the time these districts were examined very few of the gold-silver veins were being mined or developed and there was little opportunity to study the changes at depth. The primary ore occurs as shoots in the veins, and it is difficult to tell whether the decrease in metal content with depth in individual deposits is due to surface alteration or to differences in the original ore. Nowhere in the State have operations in this type of ore been carried below 600 feet and much of them not below 300 feet. Most ore bodies contained as much metal at the outcrop or very near the surface as at any greater depth, and so far as can be learned the decrease in value with depth was general. This, however, did not cause the closing of all the mines; several were closed on account of inflows of water that were too large to be profitably pumped.

Part of the gold and silver occurred as selenide and telluride. Part of the gold was probably native and some of the silver occurred as sulphide. In alteration the silver, for the most part at least, formed chloride and the gold minerals metallic gold. A little native silver is reported from the deposits but is of slight importance. As there is no leached zone at the outcrop, it is not probable that the migration of the gold and silver was extensive.

The absence of important placers associated with the deposits might be interpreted as indicating downward migration of the gold. More probably, however, the gold, which is finely disseminated in a quartz or silicate gangue with little sulphide, has not been freed from the gangue minerals on weathering and has been carried away in the silicate débris.

SUMMARY.

The processes of oxidation have had very different effects on the different metals but have ordinarily enriched each of the principal metals in some portion of the resulting deposits by the rearrangement and removal of the constituents.

GOLD.

So far as known gold has migrated but little during oxidation, though the relative richness of some of the secondary sulphides indicates some downward movement. There has been some concentration of gold in the upper portion of the zone of oxidation by the removal of other constituents, and probably there has been some mechanical concentration at and near the surface. Perhaps the most important effect of the oxidation, however, has been to make the gold much more readily recoverable by ordinary milling treatment.

SILVER.

The migration of silver has apparently been slight, probably owing to the fact that the surface waters of most of the districts contain abundant chlorine and that the insoluble silver chloride is readily formed. The enrichment has resulted chiefly from the removal of other constituents in the upper part of the zone of oxidation. Under favorable conditions there has doubtless been some downward movement

of silver and some concentration in the zone of sulphide enrichment. The oxidation of the silver ores, however, rendered them much more amenable to milling.

COPPER.

Much of the copper ore of the State has resulted directly from oxidizing processes. The primary material in many of the deposits has proved to be of too low grade for profitable treatment. During oxidation the copper was carried downward and was precipitated at lower levels as either carbonate or secondary sulphide. The upper portion of the enriched sulphide zone was commonly altered. to native metal, oxides, and carbonates. In the early days of copper mining in the United States the carbonate and oxide ores were much more cheaply treated than the sulphide ores. When the industry became important in Utah, however, the smelting of sulphide ores was well developed, and the low-grade sulphide ores are, at present, more readily treated than oxidized ores.

LEAD.

The principal oxidation products of lead—cerusite and anglesite—are very slightly soluble, and lead has moved little during oxidation. In many of the deposits, however, the lead content in the upper portion of the deposits has been increased by the removal of other constituents, and the character of the ore has been greatly improved by the removal of objectionable constituents. This alteration was especially important in simplifying metallurgic processes for the treatment of the lead-silver ores during early development.

ZINC.

Zinc has migrated very extensively during oxidation and doubtless much of that contained in the original deposits has been dispersed and lost. Only under favorable conditions has zinc been concentrated during oxidation.

Oxidation of the primary sulphide formed the very soluble sulphate, which was carried downward. When it came into contact with limestone the metal was precipitated as the relatively insoluble carbonate or basic carbonate; and when it passed into the sulphide zone, as in the Horn Silver mine, it was deposited as secondary sulphide. Some valuable zinc deposits have resulted from the alteration, and the ores of the other metals have been improved by the removal of the zinc.

IRON.

Deposits in which the primary iron minerals were mainly oxides have been little changed by oxidation processes, but deposits composed largely of pyrite have been greatly changed. In the deposits in limestone migration of the iron has apparently been relatively slight, most of it changing to the hydrous oxide, but there has probably been some enrichment from the removal of other constituents. Some movement of the iron is indicated by its precipitation with zinc in secondary deposits. Migration of iron on a large scale is illustrated by the Tintic or Dragon iron mine, where iron derived from the oxidation of pyritized volcanic rock moved downward and formed a large replacement body in the underlying limestone. In noncalcareous rocks migration has apparently been much greater. In some places it has apparently been largely dispersed, but in other places it may have been precipitated along fissures or other openings as hydrous oxide concentrated from disseminated sulphides.

PART II.—RANGES AND DISTRICTS.

WASATCH RANGE.

REGION NORTH OF OGDEN.

By G. F. Loughlin.

BEAR RIVER RANGE.

GENERAL FEATURES.

North of Ogden, the Wasatch Mountains, as defined by the United States Geographic Board, consist of two distinct parallel ranges which are separated by depressions 4 to 10 miles wide. (See Pl. I, in pocket.) The eastern range is often called the Bear River Range or Plateau.

The Bear River Range or Plateau extends north from latitude 41° 45′ to latitude 42° 45′, between Cache Valley on the west and Bear Lake valley on the east. Its length is approximately 120 miles and its average width 10 to 15 miles.

The Bear River Range includes the Garden City or Swan Creek district in Rich County and the districts of the Hyrum-Paradise region in Cache County. (See fig. 37.) Production from these districts comprises small shipments of lead and zinc ore and a little copper ore, all low in silver and gold and typical of deposits formed remote from important igneous intrusions. The period of mineralization has not been determined from local evidence.

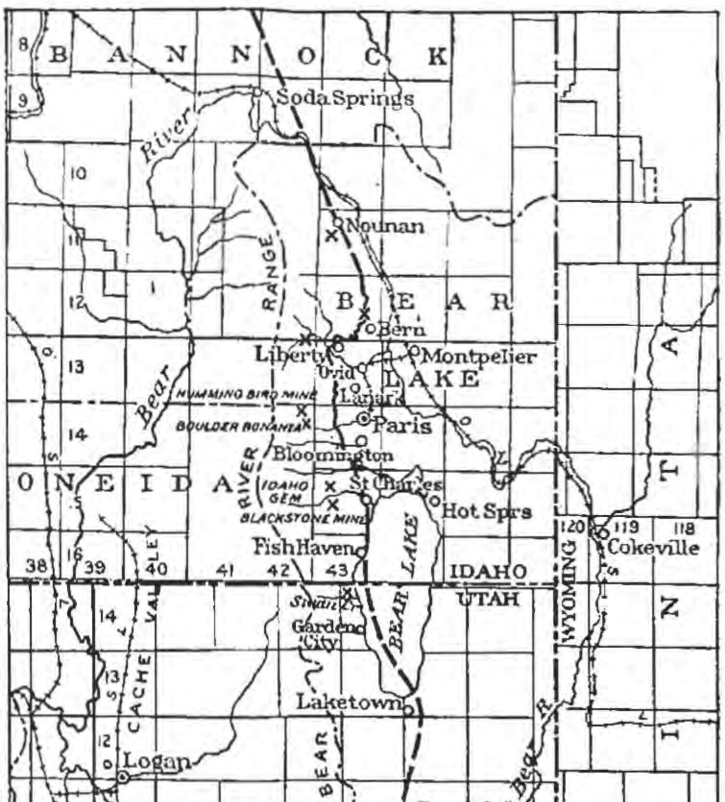


FIGURE 37.—Map showing relation of mining prospects to Bear River Range and overthrust. The margin of the overthrust block is indicated by the heavy, broken line. (After R. W. Richards.)

GEOLOGY.[1]

STRUCTURE.

The geologic structure of the range as a whole has not been worked out, but data collected by the geologists of the Hayden Survey[2] indicate that it is synclinal, the youngest rocks occupying the center of the trough. The eastern flank consists of a great overthrust block of folded and broken Middle Cambrian to Mississippian limestones and quartzites that rests on rocks in part of Triassic age. The magnitude of the thrust is indicated by the fact that it is traceable for about 100 miles, from near Woodruff, Utah, to north of Soda Springs, Idaho (see fig. 38), practically coextensive with the range itself. The direction of

[1] The notes on the geology of the Bear River Range and on the ore deposits of the eastern slope are condensed from a report by R. W. Richards, U. S. Geol. Survey Bull. 470, pp. 177–187, 1911.

[2] Peale, A. C., Geology of the Green River district: U. S. Geol. and Geog. Survey Terr. Eleventh Ann. Rept., pp. 587–589, 1879.

movement is toward the east and the maximum apparent displacement is about 10 miles. The dip of the fault plane does not average over 10°, although locally it exceeds that amount. In general the fault is not expressed in the topography, but west of Lanark, Idaho, a retreating scarp bears evidence of erosion. In the vicinity of St. Charles and Paris, Idaho, the strata along the eastern margin of the thrust block form an anticline paralleled on the west by a syncline, and the mineral deposits in that neighborhood are on the intervening monocline, which dips 20° to 30° W.

STRATIGRAPHY.

The main mass of the Bear River Range is made up of Paleozoic sediments ranging in age from Middle Cambrian to Mississippian. Rocks of probable Triassic age underlie the overthrust block on the east, and patches of Tertiary lake beds lie on the summits and in a terrace-like fringe about the lower hills. No igneous rocks are known in the range proper, but its northern end is embayed by basaltic flows of post-Pliocene and possibly late Quaternary time. The mineral deposits are found particularly at the base of the Middle Cambrian Ute limestone.

ORE DEPOSITS.

EASTERN SLOPE (SWAN CREEK DISTRICT).

The mineral deposits of the eastern slope of the Bear River Range lie in the Garden City or Swan Creek district in Utah and to the north in Idaho. They have been known and prospected for 15 or 20 years and the prospect pits are scattered from the vicinity of Woodruff, Utah, to Soda Springs, Idaho. The lead ores, which consist of galena with small amounts of cerusite and wulfenite in a gangue of iron-stained calcite and dolomite, are found at Swan Creek, Utah, and near St. Charles and Paris, Idaho. They appear to be tabular replacement deposits in limestone, more or less parallel to the bedding and cut and limited by fissures.

The copper ores consist mainly of the carbonates, azurite and malachite, in quartz veins and locally of the sulpharsenite and sulphantimonite, tennantite and tetrahedrite, in a brecciated quartz and jasper gangue. Both modes of occurrence are found in quartzites of probable Cambrian age. Igneous rocks are not associated with either the lead or the copper ores.

Shipments of ore have been made from two localities—the Boulder Bonanza-Humming Bird group, west of Paris, Idaho, and the Blackstone mine, west of St. Charles, Idaho. The shipments from the former group amount to less than 100 tons, partly lead and partly copper ore; and from the latter to about 800 tons of high-grade concentrates.

The Victoria No. 1 prospect on Swan Creek, a short distance south of the Utah-Idaho line, is said to be the center of a group of eight claims. The wall rock is massive limestone. The ore consists of malachite, azurite, accompanying barite, and calcite in a much brecciated zone approximately parallel to the stratification of the beds. Recrystallization or marbleizing of the limestone appears at the same horizon 100 yards or more to the south.

The amount of ore at this place has not yet been proved to be sufficient to be commercially valuable. Up to 1913 prospecting had been carried on for nearly 20 years. None of the deposits appear to be promising, but the locality is of interest, for it shows the continuation of the mineralized zone in association with the sedimentary rocks.

WESTERN SLOPE (HYRUM-PARADISE REGION).

By V. C. Heikes.

Hyrum is in Cache County, near the mouth of Blacksmith Fork Canyon, on a branch line of the Oregon Short Line Railroad. (See fig. 37.) Logan, the county seat, is 6 miles north, and Paradise, a small village, 4 miles south of it. All three villages are on the east side of Cache Valley, near the foothills of the Bear River Range, at altitudes of about 4,500 feet above sea level. The length of Cache Valley from Paradise to the Utah-Idaho line is nearly 50 miles, and its width ranges from 6 to 16 miles, average 12 miles. Muddy Creek, Blacksmith Fork, High Fork, Gros Bois Fork, and Logans Fork, all small streams, flow into the valley from the Bear River Mountains on the east, and Rush Creek enters it from the west.

Small amounts of ores containing gold, silver, copper, lead, and zinc have been shipped from Richmond, Smithfield, Logan, Hyrum, Paradise, and La Plata. Shipments in the early

nineties were largely of lead ore from the La Plata region, where the Sundown, La Plata, Silver King, and Lead King properties are situated.

A sheep herder is reported[1] to have found the first ore in the La Plata claim—a boulder weighing about 150 pounds, consisting principally of galena. A shaft sunk here to a depth of 165 feet and a tunnel driven for about 190 feet on the Sundown claim found no ore. At another place south of the tunnel, on the Sundown claim, some copper croppings were found and slightly developed without any particular result. It is reported that the Sunrise claim has been developed by an incline shaft 100 feet deep that shows some galena, and that the Yellow Jacket shows low-grade carbonate lead ore. According to J. F. Heald,[2] the Utah & Idaho Mining Co., predecessor of the Silver-Lead Mines Co., shipped over 8 tons of ore from the same property that averaged 76 per cent lead and 2 ounces of silver to the ton.

In 1908 the Silver-Lead Mines Co. produced from the Lead King property near Avon, a village 4 miles south of Paradise, 18 tons of ore containing 36.3 per cent of lead and 1 ounce of silver per ton. From the Lucky Star claim, at the head of the left fork of Blacksmith Fork Canyon, about 13 miles east from Hyrum, 10 tons of lead sulphide ore was shipped containing 46.3 per cent of lead, 3.9 ounces of silver per ton, and 1.5 per cent of copper and from the Tip Top claim about 17 tons of zinc carbonate averaging 29.92 per cent of zinc, 6.3 per cent of lead, and 0.6 ounce of silver per ton.

In August, 1915, a new zinc deposit was discovered about 3½ miles east of Hyrum, and about a mile south of Blacksmith Fork Canyon in an oxidized iron cropping on an old gold location known as the Moon claim. Some of the early samples assayed 42 per cent of zinc. A carload returned the owners 28 per cent of zinc and a second car about 22 per cent. With better sorting a better grade of ore might be shipped. The claim is 300 to 400 feet higher than Hyrum and is reached by steeply inclined roads. The ore is in blue limestone, with overlying quartzite (?) that dips 33° E. The thickness of the ore-bearing limestone could not be ascertained, no ex[posures] being visible. Fossils show the ag[e of] the limestone to be Carboniferous.

From observations at a few shallow open[ings] the ore appears to lie in a certain favorable [bed] of the limestone that dips toward a fis[sure] filled with oxidized iron. This fissure, wh[ich] was traceable for over a mile to the Moon [claim] outcrop, cuts the limestone beds vertic[ally]. The dark-colored iron samples carry 2.8 [per] cent of zinc, and others from lighter-col[ored] portions, 1.2 per cent of zinc.

MORGAN MOUNTAIN.

By G. F. Loughlin.

Morgan Mountain is a southward contin[ua]tion of the Bear River Range. It compr[ises] the Argenta and Morgan districts.

ARGENTA DISTRICT.

GENERAL FEATURES.

The Argenta district is about 15 miles e[ast] of Ogden and 6 miles north of Peterson station on the Union Pacific Railroad. [The] principal workings are on the slopes south [of] Little Cottonwood Creek, a tributary of We[ber] River. Three properties, owned by the C[ar]bonate Hill, Carbonate Gem, and Morg[an-]Argentine mining companies, have been [the] most active, but none of them has been worl[ked] continuously. The first shipment of ore fr[om] the Carbonate Hill mine was made in 190[?] and small shipments have been made dur[ing] every year since then. A few shipments ha[ve] been made from the Carbonate Gem. W[ork] on the Morgan-Argentine property up to 19[?] consisted only of development.

GEOLOGY.

The formations in the vicinity of the mi[nes] include pre-Cambrian granite schist and gnei[ss,] Cambrian quartzite, and Paleozoic limesto[ne.] The pre-Cambrian rocks lie west of the mi[nes] in the low foothills, and are bounded on t[he] west by Tertiary and Quaternary strata. [On] the east they are overlain by Cambrian quar[tz]ite and conglomerate which dip from vertical [to] steeply eastward. The quartzite is overl[ain] by shale, and the shale by a great thickness [of] limestone which also dips steeply eastwa[rd.] The lower limestone beds have the litholog[ic]

[1] Sloan, R. W., Handbook of the mines of Utah, Salt Lake City, 1895.
[2] Personal communication.

[a] Heikes, V. C., U. S. Geol. Survey Mineral Resources, 1905, p. 320, [...]

characters common to the Middle Cambrian limestones of Utah. The upper (eastern) beds contain lower Mississippian fossils, the only fossils found in the district. Between the Mississippian and Cambrian other ages may be represented, but the strata are poorly exposed and largely concealed beneath brush and reddish disintegrated material that may be remnants of Tertiary (Wasatch) beds. The Mississippian limestone passes upward into a series of limestone, limy sandstone, and shale beds, many of them red, which probably represent the Morgan formation. These beds are overlain on the east and southeast by a bed of conglomerate with abundant well-rounded pebbles, which dips at a lower angle to the east and is overlain by the Weber quartzite. No igneous rocks, other than the pre-Cambrian granite, have been found.

ORE DEPOSITS.

The deposits thus far worked or prospected are in the limestone. Those of the Carbonate Hill and Carbonate Gem mines are in Cambrian limestone; those of the Morgan Argentine are in the Morgan (?) formation. The ore occurs in small bunches along the bedding and along fissures of northwest, northeast, and east-west trends. The ore minerals are galena, cerusite, pyrite, and limonite: the principal gangue minerals are barite and more or less calcite. Fragments of smithsonite-limonite ore were found on the lower dump, and jarosite was found on the upper dumps of the Carbonate Hill mine. The sulphide ore, so far as seen, consists of fine-grained galena and pyrite in about equal volumes; the oxidized ore is a mixture of cerusite and limonite, the latter in such large amount that some shipments of the ore were smelted free of charge because of their fluxing qualities. The average contents of shipments from the Carbonate Hill mine are silver, 2.7 ounces to the ton; lead, 16.9 per cent; insoluble, 17.2 per cent; zinc, 2.7 per cent; sulphur, 0.5 per cent; iron 33.4 per cent. One mineralized outcrop on the Morgan-Argentine property is said to have yielded on assay 4 per cent of copper, but assays of several samples show the ore from this property to be generally similar to that from the Carbonate Hill mine.

The mineral composition of the ore, its low silver content, and the general absence of quartz in the gangue are characteristic of ore bodies remote from intrusive igneous bodies. The small size of the ore shoots thus far found is evidently due to the unfavorable character of the inclosing rock. The Cambrian limestones and also the limestone beds of the reddish Morgan (?) formation are prevailingly impure and of dense texture, and therefore not very susceptible of replacement by this type of ore. More favorable limestone beds are present in the Mississippian beds below the Morgan (?) formation, but so far as known no mineralized fissures have been found in them.

MORGAN DISTRICT.

GENERAL FEATURES.

The Morgan district is north and east of Morgan on the Union Pacific Railroad. Active prospecting in 1913 was confined to the claims north and northwest of the town and within 4 miles northwest of Morgan station. One property, the Chicago-Utah, about 8 miles east of the town, was active a few years earlier. Small quantities of ore containing copper and silver were shipped from one or more of the properties in 1907 and 1908.

GEOLOGY.

The geologic formations in the district trend north and most of them dip east. They include in ascending order the lower Mississippian or Madison limestone, which includes a few red shaly and sandy beds, the Morgan formation, prevailingly red, the Weber quartzite, and the Park City formation, which includes the principal phosphate beds of the region. The workings of the Morgan-Crescent Mining Co. are in the Madison limestone; those of the Chicago-Utah are said to be east of the phosphate beds. No igneous rocks were seen by the writer, and the only ones reported are a few "quartz porphyry" dikes east of the Morgan Crescent mine.

ORE DEPOSITS.

All the deposits near Morgan station are of the same general type. On the Iron King claim, about 4 miles northwest of Morgan, the principal showing is a vein of coarse-grained calcite, whose outcrop strikes about N. 30° W. obliquely across the northward-trending country rock. Its continuity is concealed beneath brush and talus, and no work has been

done along it, other than a shallow pit at the outcrop. The limestone and shale along it are crisscrossed with calcite veinlets, which are accompanied by small streaks and spots of oxidized copper minerals. Close by the vein a shale bed, similarly mineralized and dipping 70° W., has been prospected by an inclined shaft 80 feet deep, and has yielded specimens said to assay very high in gold. No continuous ore streaks have been found, however. The shale has also been prospected by a tunnel, at a level 300 feet lower than the shaft collar, and is found to contain local sprinklings of very fine pyrite crystals, perhaps accompanied by fine specks of gold, and by a few small lenses of quartz. One specimen is said to have assayed over $1,000 in gold.

The Red Eagle and Morgan Consolidated claims, about a mile north of Morgan, are on what appears to be a single vein striking N. 45° W., which consists of crushed fragments of impure limestone and shale cemented by inconspicuous quartz and by calcite which contains small thickly scattered pyrite crystals. No replacement of the rock fragments by vein matter is evident. The width of the vein on the Red Eagle claim is about 4 feet, and on the Morgan Consolidated workings is said to reach a maximum of 12 feet. The vein near the surface is oxidized to a yellow ocherous material with a few green copper stains and is said to have assayed $50 a ton, presumably in copper, silver, and gold. No assays of the sulphide ore are available. The character of the ore suggests that it may be concentrated successfully.

The Morgan-Crescent claim lies east of the Red Eagle, well up the slope of a high hill. The only deposit worked up to 1913 was a body of copper-silver-gold ore that had replaced a bed of relatively pure limestone in a series of limy shales and quartzite. It is said to have yielded about $45 a ton, but assays of small samples reported by the American Smelting & Refining Co. show only gold 0.6 ounce and silver 0.2 to 0.3 ounce to the ton; copper, 0.1 per cent; iron, 53.3 to 55.6 per cent; insoluble, 4.9 to 8 per cent. The deposit is marked at the surface by a strong outcrop of limonite accompanied by malachite, azurite, chrysocolla, tenorite, cuprite, and native copper. The stopes extend a short distance down the dip into the hill and end in short tongues and pipes. The only primary (hypogene minerals recognized in the main ore bod fine-grained pyrite and a few doubtful t of chalcopyrite. A small body of marc possibly of secondary (supergene) origin, found at the down-dip end of one stope, small amounts of galena are found along vertical fissures a short distance beyond down-dip ends of the stopes. The ga minerals include, besides altered limest small amounts of quartz, barite, and calci the main stopes, and calcite associated galena along the vertical fissures.

The source of the main ore body is in do No connections between it and the gal calcite fissures have been found. It ther can only be suggested that before the s slope of the hill had been eroded back t present position, solutions similar to which formed the Red Eagle vein rose alo fissure and spread along a limestone bed; subsequent erosion has worn away the con tion between the bedded deposit and fissure, concealing the fissure beneath ta and that oxidation and downward concen tion along the dip of the ore body accompa the erosion and produced a small isol deposit of high-grade copper-gold-silver

The mineralogy of the ores in the Mo district differs from that of most others ren from intrusive igneous bodies in that cop instead of lead or zinc, is the principal metal present and that the gold-silver c tent is unusually high. The gold-silver c tent, however, and the copper content of Morgan-Crescent mine represent second concentration and are not fair indications the amount of these metals in unoxidi ore. The unoxidized ore of the Red E vein indicates a low copper content, and i probable that the precious-metal content also low. The absence of marked repla ment action by unoxidized ore indicates t the ore-forming solutions were weak, and t is in keeping with the small amount of qua and the prominence of calcite in the gang The small amount of galena and calcite no along the fissures in the Morgan-Cresc workings are a further indication of we relatively cool solutions. Marcasite is exceptional in Utah ore deposits to be of mu significance, but its modes of occurrence general point to deposition at low tempe

tures. It is improbable that such solutions formed extensive ore bodies, except where excessive shattering, as in the Red Eagle fissure, or an easily permeable limestone bed, as at the Morgan-Crescent mine, provided exceptional conditions.

BOX ELDER, WILLARD, AND WEBER DISTRICTS.

GEOLOGY.

By G. F. Loughlin.

The geology of the Box Elder, Willard, and Weber districts is most conveniently considered as a unit. The formations represented include

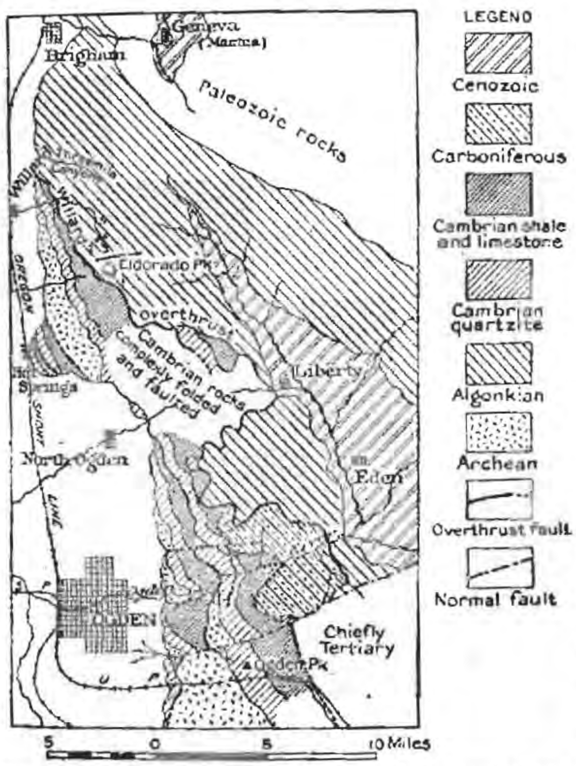


FIGURE 38.—Geologic sketch map of Wasatch Range proper between Ogden and Brigham. (After Blackwelder, with minor additions.)

Archean, Algonkian, Cambrian, Carboniferous, and Tertiary rocks, but their relations are complicated by extensive overthrusts and large east-west, or transverse, normal faults.

Archean granite extends southward along the range from Willard to a point east of Hot Springs and is exposed in smaller masses along the foothills east of Ogden. (See fig. 38.) A larger mass of it extends from a point near Ogden southward for several miles. East of Hot Springs it is overthrust upon Cambrian limestone.

The Algonkian outcrops in a broad belt that extends southeastward from Brigham beyond the latitude of Ogden. On the east it is overlain unconformably by Cambrian quartzite; on the west it is overthrust upon Cambrian and Carboniferous rocks. The Algonkian in the Willard (and also in the Sierra Madre district, pp. 223–224) comprises in ascending order: (1) A lower quartzite, exposed on Eldorado Peak, in the Sierra Madre district, and containing in its lower part two prominent beds of ferruginous schist; (2) a slate full of quartz lenses, well exposed on the divide at the head of Willard Canyon and separated from the lower quartzite by an east-west fault along the north side of Eldorado Peak; (3) a green schist specked with minute black crystals of an amphibole which extends southeastward across the cirque at the head of Willard Canyon; (4) a dark-gray finely "knotted" schist that forms the southwest slope of the canyon and passes just north of the cirques; and (5) an upper quartzite with interbeds and partings of mica schist that forms the floor of lower Willard Canyon, and the area to the north and east. (See fig. 38.)

The Cambrian includes two formations: The Brigham quartzite below and a series of shales and limestones above. It occurs in two belts, one extending southeastward from near Brigham, and one extending more southward from Willard to Ogden and beyond. Ordovician and later strata lie east of the Cambrian limestones near Geneva (Mantua) but are not present in the mineralized part of the region.

The Carboniferous is limited to an area over a mile wide, which extends for about a mile both north and south of Ogden River. It is overridden on the east by Algonkian rocks and appears on the west to be overthrust upon Cambrian limestone. Tertiary conglomerate and sandstone cover an extensive area east of the range. (See fig. 38.)

ORE DEPOSITS.

The mineral deposits include veins in all the different kinds of rocks, and a few bedded replacements in Cambrian limestone. Very little ore, however, has been shipped from any of these deposits. The principal metals are copper, lead, and zinc, and small amounts of silver and gold. Magnetite deposits have been prospected in the Willard district.

BOX ELDER DISTRICT.

By G. F. Loughlin and V. C. Heikes.

The Box Elder district, organized October 2, 1889, is in Box Elder County, near Bakers, a station on the Oregon Short Line Railroad. One property, known as the Mineral Ridge, worked for years under different names, has an aerial tramway, a mill, and other improvements, but has never reported any production to the United States Geological Survey. The property lies about 4 miles north of Brigham, on the front slope of the Wasatch Range. Its workings consist of three short tunnels and a few shallow pits along a crushed zone which strikes N. 60° E. and dips about 50° SE. The country rock is dark bluish-gray Cambrian limestone, part dolomitic and part shaly. The crushed zone is 25 to 30 feet wide and is stained yellowish brown. The only evidence of mineralization at the surface is a few veins of columnar and banded calcite, or travertine, which is common in the vicinity of lead-zinc ores low in silver.

A small production of copper ore, carrying gold and silver, was reported from the Box Elder district in 1908 as having been sold to the Independent Smelting Co., which operated a furnace near Ogden.

WILLARD DISTRICT.

By G. F. Loughlin.

The Willard mining district includes a considerable area east of Willard and on both sides of Willard Canyon. (See fig. 38.) The prospected deposits include magnetite, hematite, copper, and lead ores.

Magnetite bodies have been prospected on the Twin Pine and Mormon Girl claims, which are on the south slope at the head of Threemile Canyon, the first canyon north of Willard Canyon. The ore bodies are local replacements of quartzite beds, which dip steeply eastward. That on the Mormon Girl claim contains films of malachite and azurite filling cracks and is said to assay about 5 per cent copper. It is opened by a shallow inclined shaft and a 70-foot tunnel, which show the ore to be a replacement of shattered quartzite. Quartz-muscovite veins trending in various directions are associated with the ore body.

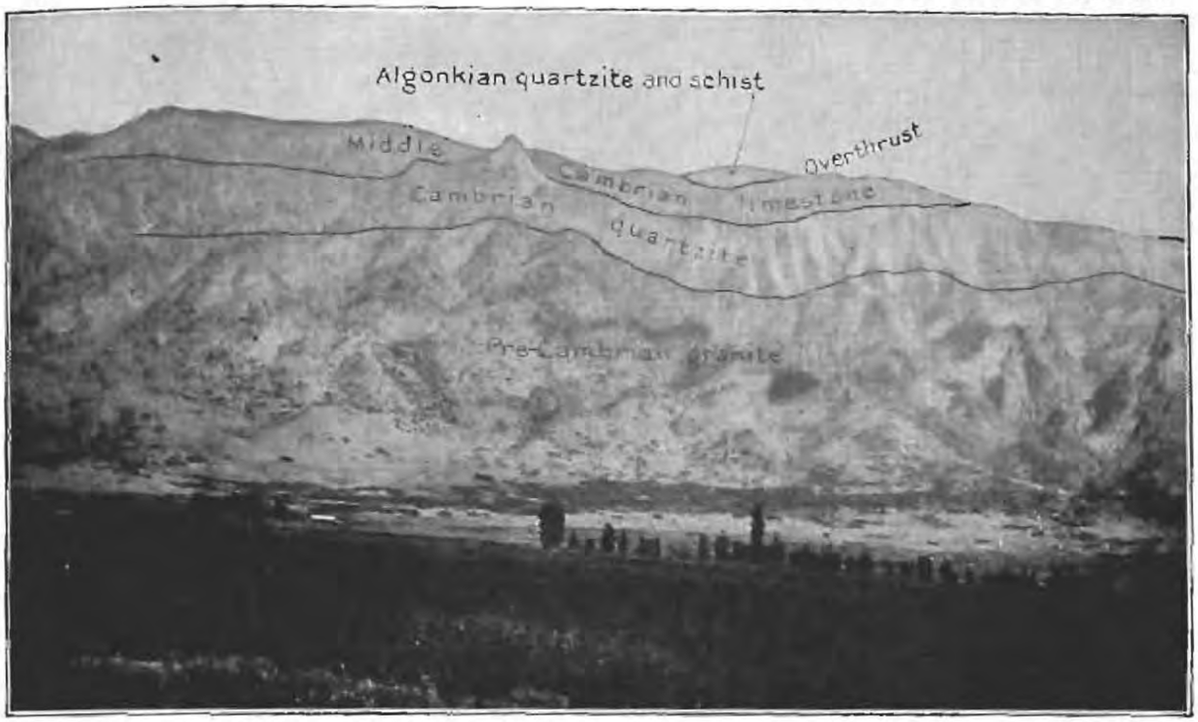
Specular hematite was noted in two beds of ferruginous schist in the lower quartzite member of the Algonkian. Their horizon extends from the foothills west of Willard southward into the Sierra Madre district, where they are exposed high on the west slope of Eldorado Peak. Microscopic examination of a specimen from one of these beds showed that it consisted mainly of quartz and hematite and a little muscovite. The hematite averaged about 25 per cent, by volume, of the rock.

Copper and lead minerals have been found in the same vein, as on the Ogden Boilermakers prospect, and in separate veins, as on the Overland and Silver Queen claims. On the Ogden Boilermakers claim, which lies over the divide east of the head of Threemile Canyon, the upper Algonkian quartzite is cut on the surface by a vien of white quartz, which contains scattered granular bunches of galena and a little tetrahedrite and is stained with malachite, azurite, and a little yellow earthy material like bindheimite. A tunnel 1,200 feet long was driven to cut the ore at considerable depth below the outcrop but failed to find the downward continuation of the vein.

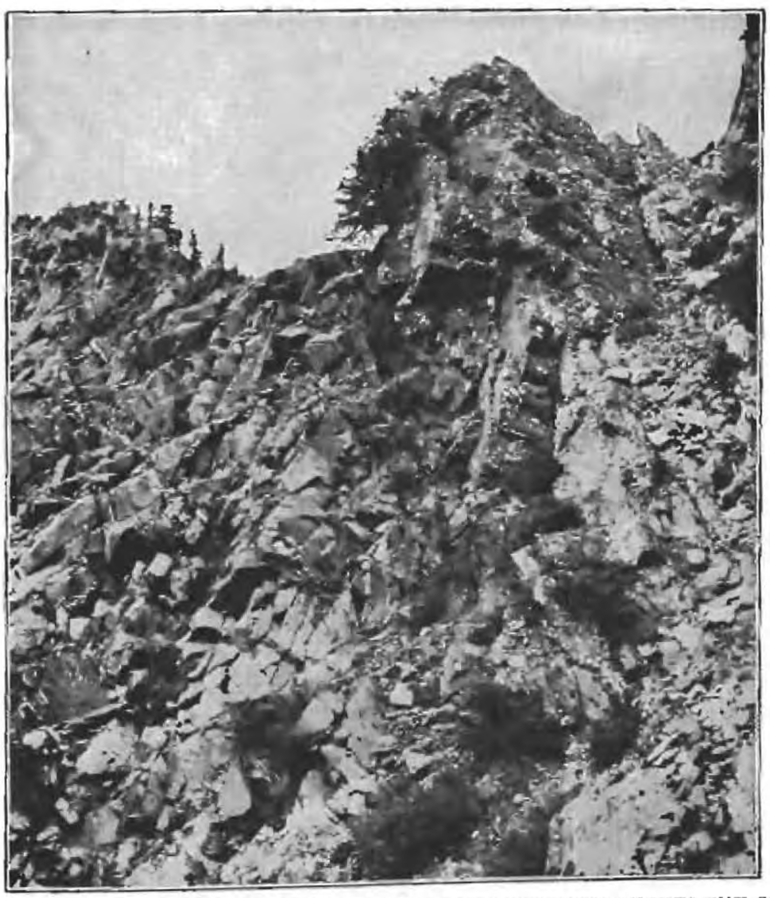
On the Overland claim at the head of Threemile Canyon the upper Algonkian quartzite is mineralized along a bed 3 feet or more thick which dips 30° SE. The ore minerals are pyrite, malachite, and azurite, a little chalcopyrite and tetrahedrite, and, it is reported, small amounts of gold and silver.

On the Silver Queen, which lies on the south slope of Willard Canyon about a mile from its mouth, the upper Algonkian quartzite is cut by a vein, of probable north-south trend, composed of white quartz and fine-grained laminated galena. The vein in places is sheared and shattered, which probably accounts for the laminated appearance of the galena. The vein, when seen in 1913, was opened by two short tunnels, neither of which had penetrated beyond the broken superficial material.

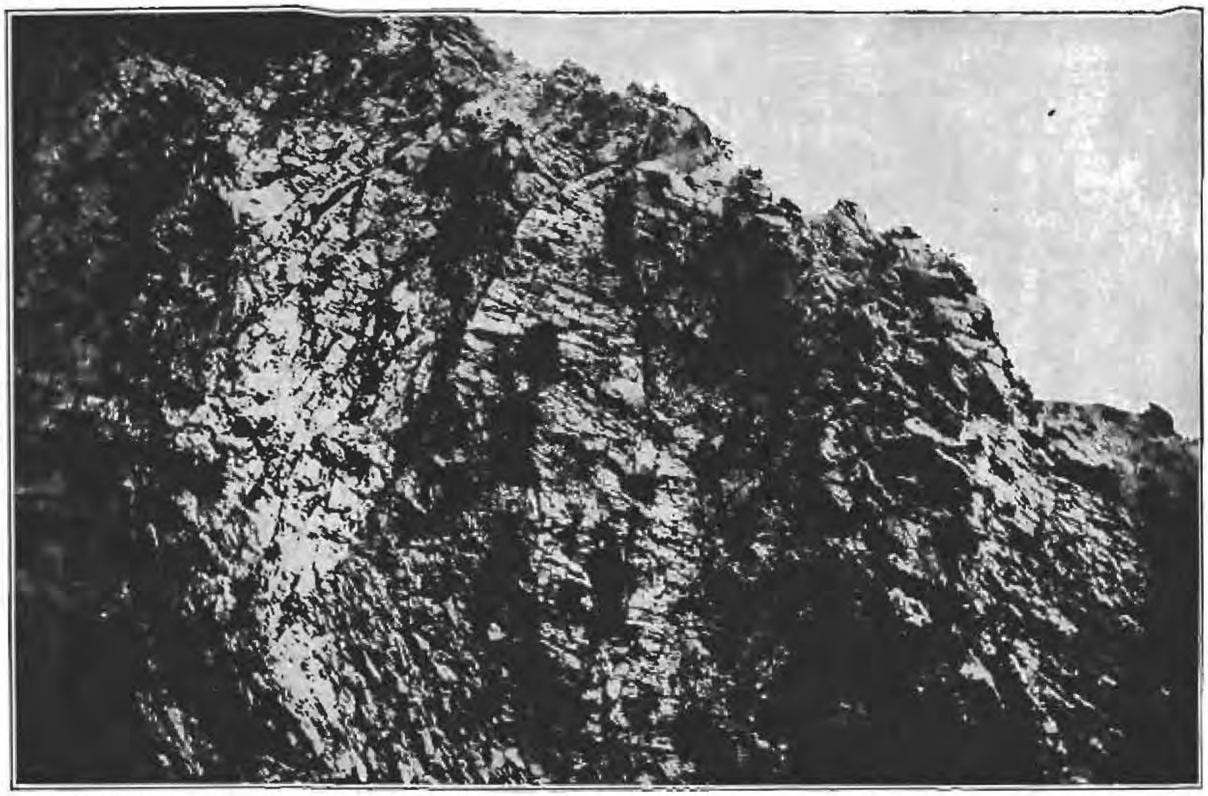
These deposits in general are of promise, so far as mineral composition is concerned, but the lack of persistence of some and the small dimensions of others are not encouraging. Too little prospecting has been done to warrant a very positive opinion as to the extent of mineralization.



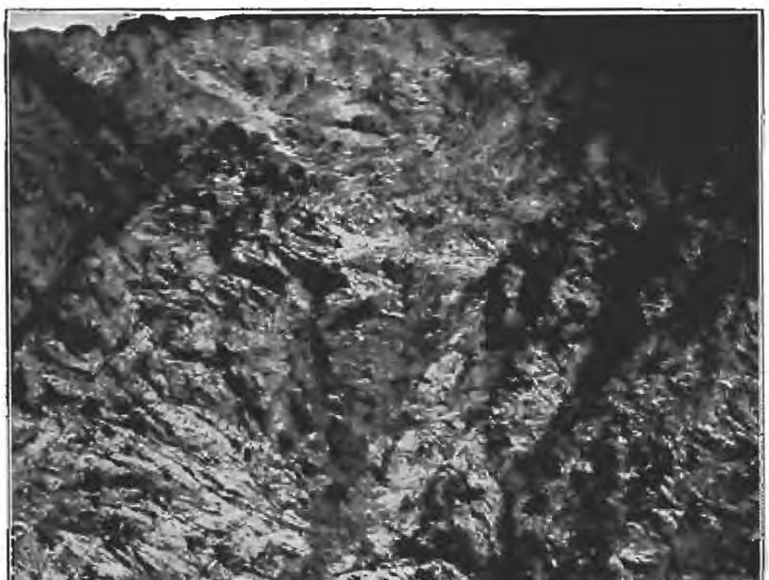
A. WEST FRONT OF WASATCH RANGE IN SIERRA MADRE DISTRICT, SHOWING GEOLOGIC FORMATIONS.



B. UNCONFORMITY SHOWING PRE-CAMBRIAN GRANITE AND PEGMATITE DIKES CUT OFF BY BASAL CAMBRIAN CONGLOMERATE, SIERRA MADRE DISTRICT.



A. UNDULATORY VERTICAL FISSURES (TIGHT) AND HORIZONTAL FISSURES WITH QUARTZ AND CHLORITE IN PRE-CAMBRIAN GRANITE, SIERRA MADRE DISTRICT.



B. SANTA MARIA MINERALIZED FISSURE IN PRE-CAMBRIAN GRANITE, SIERRA MADRE DISTRICT.

Fissure extends upward from cabin.

WEBER DISTRICT.

By V. C. Heikes.

The Weber district, in Weber County, known in 1860 as the Junction district, is 2 miles northeast of Ogden. Huntley[1] reports that it was organized in February, 1878, and in 1881 contained about 130 locations, all mere prospects. A company organized to work large deposits of hematite and magnetite ore said to exist from 3 to 8 miles north of Ogden, built a furnace and ran for a week in 1876.

Small outcrops of mineralized rock, containing barite, fluorite, quartz, and copper minerals, are said to occur east and northeast of Ogden, but only one serious attempt at prospecting has been undertaken in recent years. This was on the Ogden Buckhorn Mining Co.'s property in Cold Water Canyon, east of Ogden. The deposit is said to be a vein between quartzite and limestone and to contain copper ore with low gold and silver content, mostly of milling grade.[2] No shipments have been reported.

SIERRA MADRE DISTRICT.

By G. F. Loughlin.

The Sierra Madre district lies on the west slope of the Wasatch Range northeast of Hot Springs and 10 miles north of Ogden. (See fig. 38 and Pl. XXV, *A*.) From 1901 to 1905, inclusive, the production as reported was 205 tons of ore, containing $100 in gold, 152 ounces of silver, and 3,387 pounds of copper; total value $996. No lead production was reported.

GEOLOGY.

The geology of the district is much the same as that of the Box Elder, Weber, and Willard districts. (See p. 221.) Archean granite forms the lower front slopes of the range, Cambrian quartzite a central band, and Cambrian shale and limestone an upper band, which is overridden almost at the summit, by Algonkian quartzite.

PRE-CAMBRIAN ROCKS.

The granite, or granodiorite, is gray to pink, medium grained, and massive to gneissoid in structure. It consists essentially of plagioclase (oligoclase to andesine), microcline, quartz, hornblende, and biotite. Plagioclase is commonly somewhat altered to sericite, and hornblende and biotite to chlorite, but alteration as a rule is not far advanced. In places feldspars and quartz and a little magnetite form small rounded or orbicular segregations, but practically no biotite or hornblende are present. The granite contains short dikelike bodies of dark-green, rather fine grained rock, which proves under the microscope to be a special variety of the granite, consisting of about 50 per cent quartz, 30 per cent altered feldspar (chiefly plagioclase), and 20 per cent altered biotite. The feldspar is altered to an aggregate of quartz, sericite, chlorite, and a little epidote; the biotite to chlorite, sericite, and titanite. Pegmatite veins are abundant in the granite, following foliation planes, shear zones, with micaceous borders, and strike and dip fissures, and cutting the dark-green dikelike bodies. The pegmatites contain the same essential minerals as the granite; in some of them small amounts of pyrite and perhaps chalcopyrite were noted. The pre-Cambrian age of the pegmatite is shown (see Pl. XXV, *B*) by a pegmatite dike in the granite which is cut off by a basal conglomerate bed at the unconformable contact with the Cambrian.

Several short veins, 5 inches or less in thickness, composed of quartz and chlorite and a little pyrite and chalcopyrite, follow for the most part nearly horizontal fractures that dip 10° to 20° W. and are distinctly later than the pegmatite. The probable pre-Cambrian age of these veins is indicated by some chlorite-stained quartz pebbles in conglomerate beds of the Cambrian quartzite, though these may have been derived from chloritized pegmatite veins. The quartz-chlorite veins however are distinct from the persistent mineralized fissures that have been extensively prospected.

The granite is complexly fissured. Some of the fissures (see Pl. XXVI, *A*) are of undulating trend and "tight." Others are nearly horizontal and contain quartz-chlorite veins. Still others (see Pl. XXVI, *B*) are relatively straight, trend either approximately north or east, are nearly vertical, and are mineralized. They pass upward into the quartzite. One prominent north-south fissure (the "cross-country" vein) in Eldorado Canyon, which appears to offset the east-west fissures is said

[1] Precious metals: Tenth Census U. S., vol. 13, p. 484, 1885.
[2] Salt Lake Min. Rev., vol. 9, June 15, 1907.

to extend for a considerable distance. (See below.)

The Algonkian quartzite at the summit of the ridge, above the overthrust, is not closely associated with important mineralization. (See also p. 222.)

CAMBRIAN ROCKS.

The Cambrian quartzite varies in color and texture. The basal beds contain considerable conglomerate (see Pl. XXV, *A*), which also appears less conspicuously at higher levels. The conglomerates are composed of white pebbles and a few red, jasper-like pebbles of rhyolite porphyry in a dark-green chloritic matrix, which turns brown on weathering. Some beds contain a conspicuous amount of dark-gray hematite (martite) grains, which were probably derived from the rather large magnetite grains in the pre-Cambrian pegmatite veins. The finer-grained, or typical, quartzite beds range in color from light gray to greenish and to red or brown. Many of them are separated by greenish-gray, red, or brown shale partings. The thickness of the quartzite was not measured but is roughly estimated at 1,000 feet.

A narrow band of shale overlies the quartzite and is overlain by limestone with intercalated beds of shale. The limestone for the most part is of mottled blue and yellowish color and of argillaceous composition but includes near its base a narrow band of relatively pure dolomite, which is dark gray except where bleached by alteration. This bed is the wall rock of the ore body in the Eldorado mine. It is overlain and underlain by beds of shale.

ORE DEPOSITS.

The mineral deposits include veins or mineralized fissures in granite, and bedded replacements in limestone, both of which are attributed to the same period of mineralization.

DEPOSITS IN GRANITE.

The mineralized fissures in the granite lie in north and in east trending systems, which appear to be of contemporaneous mineralization. The north-trending "cross-country" vein which crosses the Napoleon-Maghera group of claims differs in mineral composition from the others and deflects intersecting east-west fissures. The amount of the deflection, however, is neither uniform nor proportional, and it is doubtful if the cross-country vein actually faults the east-west fissures.

The mineralized fissures, except the "cross-country" vein, are marked by an impregnation of the granite with fine crystals of pyrite. The pyrite appears mostly to have replaced the hornblende and biotite, and the impregnated rock has a lighter color than ordinary. It also forms scattered grains or microscopic veinlets in feldspar and locally in quartz. Streaks or lenses of chalcopyrite, in part oxidized, accompany the pyrite in places. Oxidized copper minerals have been reported, but none were seen by the writer. The gangue minerals introduced with the pyrite are microscopic sericite and quartz. The sericite replaces biotite and in places plagioclase; the quartz is in part associated with sericite and pyrite and also forms barren veinlets. At one place in Eldorado Canyon, where a local enlargement of the King Solomon vein is intersected by the "cross-country" vein, dolomite and calcite and a little galena and zinc blende accompany the pyrite, showing similarity in composition between the mineralized fissures in the granite and the bed replacements in the limestone.

Mineralization in the granite varies from a mere streak of pyritic or limonitic material along the fissure to zones several feet wide. The greatest width noted was 40 feet, at a coalescence of fissures on the King Solomon vein in Eldorado Canyon. The mineralized rock is said to be for the most part of milling grade, although small shoots of copper ore of shipping grade have been reported. Assays of samples from the Illinois tunnel on the Napoleon-Maghera group in 1913 show from nil to a trace in gold, nil to 0.32 ounce of silver to the ton, and nil to 2.51 per cent copper. The ore produced from 1901 to 1905, inclusive, averaged \$0.50 in gold and 7.5 ounces of silver to the ton, and 0.85 per cent copper.

The "cross-country" vein was seen only on the north wall of Eldorado Canyon, where it consists of barren calcite, which forms scalenohedral crystals around cavities and apparently represents the latest phase of mineralization after the ore minerals had been deposited.

DEPOSITS IN LIMESTONE.

Some of the east-west veins in the granite have been traced upward through the quartz into the shale and limestone. (See fig. 39.) The

showings along them are not promising in the quartzite and shale but are so in the dolomite bed in the lower part of the limestone. The mineralized rock is in the upper part of the dolomite, and, as seen on the Eldorado property, is indicated by a bleaching of the rock from dark bluish to white. Their upper contacts end abruptly along the shale contact at the top of the dolomite; the lower contact is irregular and extends downward along zones of shattering into the underlying shale. It is said that mineralization has been noted at intervals along this horizon for 3 miles but no noteworthy prospecting has been reported except on the Eldorado property.

The ore consists of varying amounts of fine-grained galena, zinc blende, and pyrite, oxidized in places, in a gangue of quartz, a little sericite, and locally coarse-grained white dolomite. Calcite forms veinlets in the bleached dolomite rock and the coarse-grained dolomite. The quartz and sericite are inconspicuous, but microscopic examination shows that they may amount to 25 per cent by volume of the ore body. There is some evidence that mineralization took place in two stages—the first marked by replacement of the dolomite rock by fine-grained cherty quartz; the second by further replacement of the rock by ore minerals, quartz, and sericite. Microscopic fragments of quartz of the first stage have been found in some of the sulphide ore but not in all of it. Local deposition of the coarse-grained dolomite was probably contemporaneous with the second stage. A little fluorite is said to have been found in the ore horizon, but none was seen in the Eldorado workings.

The ore occurs in irregular bunches along the dolomite bed, and in the largest workings on the Eldorado property has been followed for about 100 feet north along the strike and an equal distance down the eastward dip. The assay records following show the variation in composition of the ore.

The first two of these represent bunches of ore with galena greatly predominating; the third a nearly pure mixture of pyrite and quartz; the fourth a segregation of zinc blende.

Assays of ore from the Eldorado mine, Sierra Madre district.

Gold.	Silver.	Lead.	Copper.	Insoluble.	Zinc.	Sulphur.	Iron.
	Oz.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Trace.	4.0	56.0	Trace.	22.7	3.2	12.6	2.6
None.	1.6	23.3	Trace.	53.1	4.9	10.1	4.8
None.	Trace.	None.	Trace.	41.6	2.9	26.5	24.4
None.	1.2	None.	(a)	2.7	46.47	(a)	3.0

a Not determined.

Samples of mineralized rock intervening between ore bunches range in content from a trace to an ounce of silver to the ton and from 4 to 5 per cent each of lead and zinc. The success of working this deposit depends largely on the careful separation of the lead and zinc ores and in the elimination of gangue matter from material shipped.

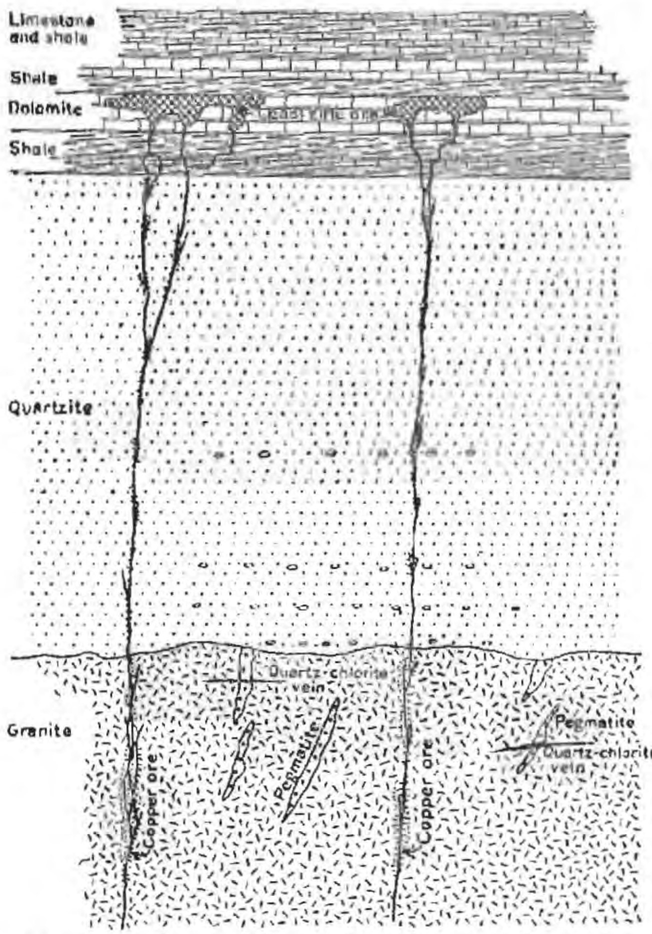


FIGURE 39.—Section showing relations between deposits in dolomite and granite, Sierra Madre district.

CONCLUSIONS.

The character of the mineralization, both in the granite and in the dolomite, point to the action of weak solutions remote from their

source. The failure of ore and gangue minerals to replace the plagioclase of the granite more extensively and their practically complete inability to replace the microcline indicate lack of concentration and scarcity of strong mineralizing elements like fluorine and carbon dioxide. The small amounts of secondary sericite, quartz, dolomite, and calcite in the mineralized zones of the granite may be regarded as merely recrystallized and more or less transferred constituents of plagioclase and biotite that were replaced by the pyrite and other sulphides, and the only elements that must have been introduced are sulphur, a little copper, lead, and zinc, some traces of silver and gold, and perhaps a little iron.

In the dolomite horizon the secondary dolomite and calcite may be regarded as of essentially local origin, and the quartz as having been derived wholly or in part from the mineralized zones in the underlying granite and quartzite. Only the metals and sulphur were necessarily brought in from great depths. The texture of the dolomite rock, its freedom from insoluble impurities other than a little carbon and very little quartz, and its favorable position between shale beds are such that solutions strong in silica and metals would have caused extensive replacement instead of the mineralization of only a small fraction of the rock, and the failure, even in this fraction, to form continuous shoots. This statement does not imply that workable ore bodies do not occur in the dolomite, but merely that most shoots in it are probably small.

REGION BETWEEN OGDEN AND SALT LAKE CITY.

By G. F. LOUGHLIN and V. C. HEIKES.

The Hardscrabble (Mill Creek), Farmington, and Hot Springs districts lie between the latitudes of Ogden and Salt Lake, in Morgan, Davis, and Salt Lake counties. Some of them have made small shipments but none has been consistently productive, and each at present is represented by only a few small operations or is idle.

HARDSCRABBLE (MILL CREEK) DISTRICT.

By V. C. HEIKES.

Hardscrabble (Mill Creek) district, 10 miles southwest of Morgan on the Union Pacific Railroad, was organized February 11, 1893. Long before this, however, the claims of the Norway Iron Mining & Manufacturing Co. (incorporated Nov. 19, 1879) were operated, yielding some iron ore containing 56.12 to 65.08 per cent of iron. A sample of brown ore from the Norway group contained:[1] Iron, 56 per cent; silica, 3 per cent; carbonate of lime, 4.5 per cent; alumina, 4.3 per cent; sulphur, trace. Some of this ore was tried in the experimental iron furnace during the eighties at Ogden.[2]

Previous to 1900 no records are available of the iron ore shipped out of the district for testing at the iron works (operated for only a few weeks) near Ogden and the several car lots shipped to different smelters as flux.

FARMINGTON DISTRICT.

By G. F. LOUGHLIN.

The Farmington district lies east of the towns of Farmington and Centerville. Three properties have been prospected, but no shipments had been made up to 1913, and only one was then active.

GEOLOGY.

The country rock is a complex of pre-Cambrian schists and gneisses, cut by numerous dikes and sills of pegmatite. The foliation dips west at a low angle along the range front, but 2 miles to the east, opposite Centerville, it arches gently over to an eastward dip.

ORE DEPOSITS.

The most promising deposit seen by the writer was a vein of copper ore on the prospect of the Buckland Mining & Development Co., east of Centerville, on the north side of Parish Canyon, about 3 miles from its mouth. Seven veins are said to have been found on the property, three of which have been prospected to a depth of 200 feet or more. The principal work has been done on a vein which enters along the north canyon slope and has been traced for about a mile within the company's property, and for about a mile more outside of it. Within the property the vein strikes about east and is remarkably straight, cutting squarely across the foliation of the inclosing gneiss. Its dip is 60°–90° N. Its maximum exposed thickness

[1] Bishop, F. M., U. S. Geol. Survey Mineral Resources, 1883-84, p. 288, 1885.

[2] Jones, M. E., Report on the international commerce of the United States, p. 883, Bur. Statistics, 1890.

is 12 feet and at only a few places is less than 4 feet.

The vein has been prospected by an inclined shaft 50 feet deep and by two crosscut tunnels from which drifts have been run along the vein to the east and the west. The upper tunnel is short and level with the bottom of the shaft; the lower tunnel is about 500 feet long and cuts the vein 300 feet below its outcrop. The vein contents are encouraging in all the openings, but up to 1913 no assays had been made except from material near the surface, which was said to average about 10 per cent copper and a little silver.

The vein consists of chalcopyrite, pyrite, and specularite in a gangue of quartz and pyrite. No galena or blende have been found in the workings, although ore containing some galena with low silver content is said to have been found in line with the vein beyond the limits of the property. The chalcopyrite and pyrite are as a whole evenly distributed, the former in irregular grains and masses up to 4 inches and more in diameter, the latter in small scattered crystals. The specularite tends to form bunches around small cavities, which are lined with crystals of specularite and quartz. The quartz is milky and massive, containing scattered bunches of dark-green fine-grained chlorite. The vein grades laterally into quartz chlorite-pyrite rock in which the texture of the gneiss is more or less distinctly preserved.

Oxidized ore extends down to the level of the upper tunnel, which approximately marks the ground-water level. It is characterized by green copper stains and by limonite, the limonite occupying the spaces of original chalcopyrite. In the ore from the lower tunnel cracks in the chalcopyrite are filled with thin seams of chalcocite. Encouraging concentrating experiments were in progress in 1913.

The only other prospects seen by the writer were those on the Morning Star group of claims, in the front of the range due east of Farmington. Several openings have been made here on quartz-chalcopyrite veins which lie along the bedding or foliation of the schist and gneiss. One vein has been followed down on an incline (now caved) for 90 feet and is said to have yielded, about 20 years ago, a 20 to 25 ton shipment of copper-gold ore, in which the value of the gold was $14 a ton. Most of the exposed ore appears to be oxidized and consists principally of malachite and azurite, remnants of chalcopyrite and pyrite, and some cuprite.

The other prospects on the Morning Star property contain the same type of ore, but their showings are too low grade to be of much promise. A tunnel to strike some of these veins at considerable depth had been driven about 400 feet in 1913.

Several outcrops and prospects of copper ore[1] containing a little gold have been reported from the Farmington district, but no shipments have been made.

HOT SPRINGS DISTRICT.

By V. C. Heikes.

Hot Springs district extends 10 miles east and west and 5 miles north and south in the Wasatch Range, adjacent to and east of Salt Lake City. It was organized in December, 1870, and now includes the old Adams district, in Salt Lake County. According to Huntley,[2] up to the end of 1880 about 230 locations had been made, but not more than 40 were being held and worked. The country rock is limestone. The ore, said to occur in small veins, was described as a low-grade ocher containing cerusite and galena, some of which assayed 15 to 25 ounces of silver per ton, but only a few tons of which had been shipped. The principal claims were the Henry Lawrence, the General Scott, and the Magnet Iron mine, from which several hundred tons of iron flux had been shipped. No large amount of development seems to have been performed.

REGION SOUTH OF SALT LAKE CITY.

By B. S. Butler, G. F. Loughlin, and F. C. Calkins.

The richest part of the Wasatch Range lies south of the parallel of Salt Lake City. It includes the Park City, Cottonwood, American Fork, Provo, Santaquin, and Mount Nebo districts, besides a few others that have never been productive.

COTTONWOOD-PARK CITY REGION.

GENERAL FEATURES.

By F. C. Calkins.

LOCATION.

The Park City, Big and Little Cottonwood, and American Fork districts together form an irregular area whose center lies in the heart of

[1] Salt Lake Min. Rev., vol. 7, March and May, 1906.

[2] Precious metals: Tenth Census U. S., vol. 13, p. 431, 1885.

the Wasatch Range, about 20 miles southeast of Salt Lake City, in line with the east-west axis of the Uinta Mountains. The Park City district, which is east of the Wasatch divide, is shown on the Park City map published by the United States Geological Survey; the main part of the Cottonwood districts and the northern part of the American Fork district, which lie west of the divide, are represented on the Cottonwood special map. The two maps cover adjoining areas and constitute the topographic base of Plate XXVII (in pocket). The Park City district and the Cottonwood-American Fork area will be described in two separate sections, which may be prefaced by an outline of the topography and geology of the region as a whole.

TOPOGRAPHY.

The western front of the Wasatch Range in the latitude of the Cottonwood-Park City region rises abruptly from the border of Salt Lake Valley, 5,000 feet above sea level, to elevations of about 11,000 feet. The crests of the ridges between the westward-flowing streams maintain this general level for several miles to the east and bear some peaks that are nearly 11,500 feet high, but they begin gradually to decrease in height before they terminate against the main north-south divide of the range. The highest summit on this divide is Clayton Peak, which rises 10,728 feet above sea level and lies near the southwest corner of the Park City quadrangle. Eastward from the north-south crest the surface descends with moderate steepness to a zone of low hills, interspersed with parks and meadows that stand about 6,500 feet above sea level, beyond which fairly steep acclivities lead up to the western brow of the Uinta Mountains.

The principal drainage lines of this region radiate from the vicinity of Clayton Peak. The crest extending north from that summit separates the drainage basins of Jordan and Weber rivers and constitutes the main divide of a long segment of the Wasatch Range. The southward prolongation of this crest first parts the Cottonwood creeks and American Fork from Provo River, and then subsides between two branches of the Provo, a stream which rises far to the east, and south of whose canyon the range has no principal divide. The watershed between the Provo and the Weber, which extends eastward from a summit about a mile north of Clayton Peak, is the most prominent spur on the east slope of the central Wasatch and connects that range with the Uinta Mountains.

GEOLOGY.

The position of the Cottonwood-Park City region at the intersection of the Wasatch and Uinta axes is geologically as well as topographically significant. The dominant structural trend in the Wasatch Range is a little west of north. The dominant structure in the Uinta Range is an anticline whose axis runs a little north of east. The region, therefore, has been subjected to compression in two directions at right angles to each other; and the resultant effect of these forces has been the formation of a broad east-pitching anticline, which will be called, following Boutwell,[1] the Park City anticline. This fold is shown very prominently on the generalized map of the Fortieth Parallel Survey,[2] but it appears less conspicuous on Plate IV, where some details neglected by the pioneers are shown; and in the still more detailed view of a smaller area given in Plate XXVII it is further obscured by the representation of the complex faulting which appears as the most prominent structural feature. The faults are widely varied in direction, attitude, and amount of throw. The greatest of those in the Cottonwood quadrangle are two or three overthrusts dipping toward the east, and a normal fault with downthrow to the west; the greatest in the Park City quadrangle is an overthrust whose dip is westward.

This folding and faulting have deformed a series of stratified rocks which ranges in age from pre-Cambrian (Algonkian) to later Triassic or early Jurassic and whose total thickness as exposed in this part of the range is about 20,000 feet. About half this thickness belongs to the pre-Cambrian, which consists mainly of quartzites and other siliceous rocks and is probably for the most part of terrestrial origin. These ancient rocks are not very much more altered in general than the Paleozoic rocks, which lie upon them unconformably but with only a slight angular discordance. The Paleozoic rocks, which are about 6,000 feet thick, are chiefly of marine origin. Their medial and

[1] Boutwell, J. M., op. cit., p. 94.
[2] U. S. Geol. Expl. 40th Par. Atlas, map 3.

greatest part consists of limestone, but they comprise a good deal of shale and two thick formations of quartzite, one at the base and another just above the greatest body of limestone. The continuity of Paleozoic sedimentation was several times interrupted; the most distinct of the resulting unconformities lies at the base of Devonian or Carboniferous limestone, which rests in most places on one stratum or another of Cambrian limestone; but not even this unconformity is marked by strong angular discordance. The Mesozoic strata, whose total thickness in the region studied is about 4,000 feet, consist mainly of shale but include large quantities both of limestone and of sandstone. They are in part marine but may be in part of fresh-water or terrestrial origin. The Mesozoic formations are not divided from the Paleozoic strata, nor from one another, by distinct unconformities. Not until after the Jurassic period was there any vigorous deformation of the strata.

The igneous rocks of the Cottonwood-Park City region are also post-Jurassic. They include the only large post-Cambrian intrusive masses that occur in the Wasatch Range. All these masses, whose rocks range from quartz monzonite to quartz diorite porphyry, are exposed along the axis of the Park City arch. Besides the larger bodies, the region contains dikes of varied composition. The intrusive rocks are younger than the sedimentary strata, which are profoundly metamorphosed by the larger intrusive masses. Extrusive igneous rocks, chiefly andesitic lava and breccia, lie in the trough between the Wasatch and Uinta ranges and occur in the eastern part of the Park City district.

The region was subjected in the Quaternary period to vigorous alpine glaciation, as is attested by characteristic glacial deposits and sculpture.

The ore deposits were formed mainly by replacement of the sedimentary rocks—especially of Paleozoic limestones—and are associated with fissures, many of which strike nearly parallel to the general trend of the row of intrusive masses and probably were formed at the time of their intrusion. The deposits are valuable chiefly for silver, lead, zinc, gold, and copper.

COTTONWOOD-AMERICAN FORK AREA.

By F. C. Calkins.

FIELD WORK AND LITERATURE.

The Cottonwood-American Fork area lies well within the zone explored by the Fortieth Parallel Survey, whose reports and maps, published between 1870 and 1880, are still of great interest and use to every student of the geology of Utah. The middle part of the range was examined in 1869, mainly by S. F. Emmons. The fine sections in Big and Little Cottonwood canyons were regarded by him as among the most instructive in the Wasatch Mountains and formed the chief basis of important deductions drawn by Clarence King regarding the general stratigraphy of the range. These deductions are now known to be in part erroneous, the most serious errors consisting in the assignment of the post-Jurassic intrusive rocks to the Archean and in the failure to recognize the presence of overthrust faults.

J. M. Boutwell, in 1902, examined parts of the Cottonwood quadrangle in connection with his survey of the Park City district, and in his report [1] he briefly reviewed the geology of the middle Wasatch. He recognized the true nature of the intrusive rocks and mapped some overthrust faults in the Park City district, thus being the first to recognize this type of fracture in the Wasatch Mountains.

But the full importance of overthrust faulting in the structure of the range was first appreciated by Eliot Blackwelder as a result of his work near Ogden in 1909.[2] The discovery of great overthrusts in the Ogden region entailed a radical revision of the Paleozoic stratigraphy. Blackwelder's paper deserves citation here, not only because it utilizes observations made on Cottonwood Creek, but even more because of the close parallelism of his results with those obtained in the Cottonwood quadrangle, three years later, by Butler, Loughlin, and Hintze.

In 1912 a reconnaissance of several districts in the central Wasatch was made by Butler

[1] Boutwell, J. M., Geology and ore deposits of the Park City district, Utah, with contributions by L. H. Woolsey: U. S. Geol. Survey Prof. Paper 77, p. 41, 1912.

[2] Blackwelder, Eliot, New light on the geology of the Wasatch Mountains, Utah: Geol. Soc. America Bull., vol. 21, pp. 517-542, 1910

and Loughlin,[1] who prepared a geologic sketch map of the Cottonwood quadrangle. In the same year F. F. Hintze, jr., made a study of part of the quadrangle, the results of which were presented as a thesis to the faculty of Columbia University.[2] Hintze and the Survey party worked unknown to each other, but both found great overthrust faults and revised the stratigraphic scheme much as Blackwelder had revised that of the Ogden region. Their most striking results were derived from the section in Little Cottonwood Canyon, which was not studied by Blackwelder.

A firm basis had now been laid for detailed field work, which was carried on for the Geological Survey by Messrs. Butler and Hintze together in 1916 and was continued by Messrs. Butler and Calkins in 1917, but which has not yet been completed.

Collaterally with the more general geologic investigations, whose sequence has been outlined, much work has been devoted to certain special phases of the geology. The Cambrian and pre-Cambrian rocks of the Big Cottonwood section have been studied by Walcott.[3] The glacial geology of the Wasatch and Uinta ranges has been described by Atwood.[4] Descriptions of certain mines studied in 1880 were published in the report of the Tenth Census. The congressional report of the investigation of the Emma mine[5] contains testimony regarding the mine by Clarence King, J. E. Clayton, W. P. Blake, and other geologists and engineers. Other articles[6] concerning the mines have appeared in mining journals and newspapers since the recent revival of mining activity.

The most thorough geologic work that has been done in this region by any mining geologist is that of J. J. Beeson. In the years 1916–1918 Mr. Beeson mapped in detail the surface and the more important underground workings on the north side of the canyon, in the vicinity of the Emma Consolidated Copper Co.'s claims, and his work resulted in the recovery of the long-lost Emma ore body. He has published brief articles in newspapers and trade journals but no general account of his results. His unpublished material was generously placed at the service of the writers.

GEOGRAPHY.

LOCATION, SUBDIVISION, AND ACCESSIBILITY.

The Cottonwood-American Fork area, which lies on the western slope of the Wasatch Range, about 20 miles southeast of Salt Lake City and immediately southwest of the Park City district, includes the Big Cottonwood, Little Cottonwood, and American Fork districts, which contain the mines that lie in the respective drainage basins of the three principal streams whose names they bear.

The northernmost district is the Big Cottonwood, which is connected with Salt Lake Valley by a wagon road that follows Big Cottonwood Canyon and crosses the Wasatch divide to Park City. In summer an automobile stage runs from Salt Lake City to Brighton (Silver Lake), a resort near the head of the canyon, and the ores mined in the district are hauled by wagon and by auto truck to smelters in Salt Lake Valley.

The mines of the Little Cottonwood district, which lies next south, are clustered about Alta, in Little Cottonwood Canyon. The camp is reached from the west by a wagon road and by a narrow-gage railway spur from Alta to Wasatch, near the mouth of the canyon, where it connects with a standard-gage spur that joins the Denver & Rio Grande Railroad at Midvale. The portion of the spur above Wasatch was long in disuse but was relaid in 1917. It is now used, except for the period when it is blocked by snow, for conveying stage passengers, who are carried in automobiles between Salt Lake and Wasatch,

[1] Loughlin, G. F., Reconnaissance in the Wasatch Mountains, Utah: Jour. Geology, vol. 21, pp. 436–452, 1913. Butler, B. S., and Loughlin, G. F., A reconnaissance of the Cottonwood-American Fork mining region, Utah: U. S. Geol. Survey Bull. 620, pp. 165–226, 1915.

[2] Hintze, F. F., jr., A contribution to the geology of the Wasatch Mountains, Utah: New York Acad. Sci. Annals, vol. 23, pp. 85–143, pls. 1–6, 1913.

[3] Walcott, C. D., The Cambrian faunas of North America, second contribution: U. S. Geol. Survey Bull. 30, p. 38, 1886; Correlation papers—Cambrian: U. S. Geol. Survey Bull. 81, pp. 159, 319, 1891.

[4] Atwood, W. W., Glaciation of the Uinta and Wasatch mountains: U. S. Geol. Survey Prof. Paper 61, 1909.

[5] 44th Cong., 1st sess., H. Rep. 579.

[6] Ryan, G. H., The strike in the Cardiff: Salt Lake Min. Rev., Nov. 30, 1914, p. 15 (describes the relation of the newly found ore body to local geologic structure); Some Alta activities: Eng. and Min. Jour., Apr. 17, 1915, pp. 689–690 (shows that the replacement ore bodies along the limestone-quartzite contact are connected with ore-bearing fissures and describes developments in the Cardiff, Columbus Extension, and South Hecla mines); Geology and ore deposits of Miller Hill, American Fork Mining district, Utah: Salt Lake Min. Rev., vol. 19, Aug. 15, 1917 (describes the stratigraphy, structure, and ore deposits of the Miller Hill area). Howard, L. O., Mining in Utah: Min. (and Sci.) Press, Sept. 18, 1915, pp. 445–446 (describes conditions in the Big and Little Cottonwood districts, especially as regards the intrinsic value of mining shares, and gives map showing claim boundaries of principal properties).

and for transporting part of the ore. The ore from some of the mines is conveyed by aerial tramway about 5 miles to Tanners Flat, and thence about 2 miles by wagon to Wasatch, where it is transferred to the railway, but the ore from other mines is still carried from Alta to Wasatch by wagon.

The American Fork district, the southernmost of the three, is connected by wagon road with the town of American Fork, on the Denver & Rio Grande and the Los Angeles & Salt Lake railways. Its largest mines are grouped about Miller Hill, a prominence near the head of the canyon. A stage has been operated intermittently between the mines and the town of American Fork. About 16 miles of railroad was laid along the canyon in the early days but was demolished in 1878.

Most of the mines of the Cottonwood-American Fork area are contained in the Cottonwood special quadrangle, which is bounded by parallels 40° 33′ and 40° 39′ and meridians 111° 34′ and 111° 40′ and forms the western part of the area mapped in Plate XXVII. Nearly all the mines of the Big and Little Cottonwood districts lie within these limits, though the Maxwell mine, on Big Cottonwood Creek, and a few prospects on Little Cottonwood Creek, are a mile or two farther west. Some of the more productive properties on the upper part of American Fork lie less than 2 miles south of the quadrangle, and the lower part of the canyon contains some prospects and unimportant mines. The properties in the basin of Snake Creek, a tributary of the Provo rising in the southeastern part of the Cottonwood quadrangle, are described with those of the Cottonwood-American Fork area.

TOPOGRAPHY.

RELIEF AND DRAINAGE.

The principal topographic features of the Cottonwood-American Fork region are the canyons of the three main westward-flowing streams, the two ridges that lie between them, and the north-south divide of the central Wasatch, which parts their waters from those of Weber and Provo rivers. These crests and canyons are the chief lineaments of a boldly mountainous landscape. The principal summits are about 11,000 feet high and those at the very brink of the western face are even higher than those on the main divide; the main streams receive their first large branches at 8,000 to 8,500 feet above sea level and descend 3,000 feet or more in flowing 8 or 10 miles farther to the mouths of their canyons.

The Cottonwood quadrangle is so placed that the Wasatch crest divide winds in and out along its eastern border. From the north boundary of the quadrangle to Sunset Peak the crest line, which is here the eastern boundary of Salt Lake County, curves gently westward around the head of Cottonwood Creek; and at Sunset Peak, where it becomes the boundary between Wasatch and Utah counties, it turns more sharply eastward around the head of Snake Creek.

At Sunset Peak the bold ridge, locally known as the Bullion Divide, that forms the northern boundary of Utah County and of the basin of American Fork, branches westward from the main divide. The Bullion Divide leaves the Cottonwood quadrangle near the southwest corner, just beyond the Twin Peaks, whose higher summit, 11,491 feet above sea level, is the highest point within that area.

The ridge which parts the two Cottonwood creeks and may be called the Cottonwood Divide does not quite reach the Wasatch crest but joins the Bullion Divide near Sunset Peak. Thence it runs northward to what will be called hereafter Honeycomb Hill, where it turns abruptly westward. The highest point on this divide within the quadrangle is, like the Twin Peaks, close to the western boundary; it is a very steep red mountain, 11,030 feet high, which is the most impressive feature of the landscape around Alta. This peak marks the junction of the Cottonwood Divide with the bold north spur whose brow is formed by Carbonate Peak. The next spur to the east is Reade and Benson Ridge, the strongest crest of secondary rank within the quadrangle.

More than the northern half of the quadrangle lies in the open upper valley of Cottonwood Creek. Rising in the broad lake-dotted basin, made up of coalescing amphitheaters, that is overlooked by Honeycomb Hill and by Sunset and Clayton peaks, this creek flows northwestward to the corner of the quadrangle, near which it takes the general westward course that it holds in its relatively narrow and rugged lower canyon. Its longer tributaries enter from the south, heading in amphitheaters on the north slope of the Cottonwood divide.

Those to which most frequent reference will be made are Mill D South Fork and Silver Fork, whose main branch is Honeycomb Fork.

The main part of Little Cottonwood Canyon, with its headward prolongation, City Rock Gulch, forms a U-shaped trough which runs nearly straight westward from Honeycomb Hill to the front of the range. Its northern and southern tributaries are even more unequal than those of Cottonwood Canyon. From its south side, within the quadrangle, there open three hanging valleys, besides the great composite basin that is drained by the headwater branches of the main stream; its north side, on the contrary, is merely scarred by shallow gullies.

The valley of American Fork has a general southwesterly course, but its main headwater branch and Dry Fork, which rise within the quadrangle, flow eastward and southward. Mary Ellen Gulch, another branch on which there is a good deal of mining activity, heads southwest of the Silver Dipper mine, in an elbow of the eastern spur of the Twin Peaks.

GLACIAL FEATURES.

The U-shaped sections, smooth walls, and basin-like heads of most of the canyons in this area, the hanging valleys, and the numerous lakes are the unmistakable work of alpine glaciers.[1] Little Cottonwood Canyon, which illustrates every typical feature of a glacial valley, contained the longest of the Pleistocene glaciers of the central Wasatch. The ice was once 1,000 feet deep near Alta and extended downstream beyond the mouth of the canyon, where it left strong lateral moraines that are broken by recent faults.[2] The glaciers of Cottonwood Creek and American Fork reached only about halfway to the mouths of their canyons.

The heaviest glacial deposits within the quadrangle are probably those about Giles Flat, on Cottonwood Creek. Strong moraine terraces rise to the 8,750-foot contour southwest of that place, and the long spur east of it is a moraine. There is much morainic material about Alta. That on the slope north of the town has indirect economic interest because it obscures the geologic structure, the deciphering of which is likely to be of great help in exploiting the ore bodies.

WATER SUPPLY.

The region is well supplied, on the whole, with excellent water, though many of the stream beds are usually dry—a fact that is probably due in part to the prevalence of limestone, in which there may be underground channels that engulf the normal flow. The sunken streams emerge as copious cold springs on Mill D South Fork and on Silver Fork.

Each of the three main streams is made to generate electric power, which is used by several of the mines and might, if fully developed, supply all the needs not only of this mining region but of neighboring towns in Salt Lake and Utah valleys. Cottonwood Creek also furnishes part of Salt Lake City's water supply. Its flow is somewhat equalized by the utilization of several lakes as reservoirs, the largest one being formed by the damming of the Twin Lakes, which have been so raised as to form a single sheet of water.

CLIMATE AND VEGETATION.

The climate of the region is cool, and the precipitation considerable, the snowfall being so heavy that winter operations are greatly hampered and the roads are not clear until late in spring. Snow lingers on some high, shady slopes until late in summer, and in years of especially heavy snowfall a few banks may survive until they are covered by the fresh snows of autumn. Destructive snowslides are remarkably frequent. They are said to have destroyed 300 lives, besides much property, in the Little Cottonwood district alone.[3]

The frequency of slides is due largely to the improvident completeness with which the timber has been removed. Of the once heavy coniferous forest only straggling pines and firs remain in places difficult of access, and little reforestation is taking place. Aspen and scrub oak and other bushes are common in the Cottonwood basin, where the larger aspens are cut for poles and logs.

[1] Atwood, W. W., Glaciation of the Uinta and Wasatch mountains: U. S. Geol. Survey Prof. Paper 61, 1909. Describes glacial phenomena in all these canyons rather fully. It may be remarked that the "Mill A" branch of Cottonwood Creek described on p. 87 of Atwood's report is evidently Mill D South Fork and should be shown on his Plate X as lying just east of Basin 42 (Mineral Fork).

[2] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, pp. 340–347, 1890. Atwood, W. W., op. cit., p. 82, pl. 14.

[3] Palmer, Leroy, Modern Milling at Alta, Utah: Salt Lake Min. Rev., vol. 8, p. 17, 1906.

GEOLOGY.

SCOPE OF TREATMENT.

The geology of the Cottonwood-Park City region is described in the following pages with rather more detail than that of the other mining districts considered in this volume. It seems best to record here somewhat fully the information that is now in hand, much of which has been gathered since the last general account of the region was published.

This account concerns itself chiefly, though not exclusively, with the Cottonwood quadrangle, to which intensive geologic field work and mapping have been confined.

SEDIMENTARY ROCKS.

TREATMENT AND SUBDIVISION.

The shortest line that traverses all the sedimentary strata exposed in the area represented by Plate XXVII extends from the intersection of Little Cottonwood Creek with the 8,000-foot contour to the northeast corner of the Cottonwood quadrangle, which is also the northwest corner of the Park City quadrangle. All along this line the strata dip northeastward, and, although they are repeated by faulting, the oldest of them are found at the southwest, in contact with the Little Cottonwood stock of granodiorite, and the youngest at the northeast, in the corner common to the two quadrangles.

The Cottonwood quadrangle thus contains a complete section of all the sedimentary formations that occur in the Park City district, and of a great thickness of older strata besides; the geologic description of this quadrangle might therefore logically include the complete stratigraphy of the Cottonwood-Park City region. But inasmuch as the ore deposits of the Cottonwood-American Fork area lie almost wholly in the formations below the Weber quartzite, which is the lowest formation that is fully developed near Park City, it is more convenient to reserve the description of the Weber and later formations for the pages devoted to the Park City district, and to describe in the present division of the report only the strata below the Weber quartzite.

The age of the Weber quartzite is Pennsylvanian, and that of the strata below it ranges downward from Mississippian to pre-Cambrian. For the purpose of preliminary mapping and description the pre-Pennsylvanian strata have been divided into five formations, as follows:

Divisions of pre-Pennsylvanian strata.

	Age.	Dominant rock.	Maximum thickness (feet).
5	Mississippian (and Devonian?)	Limestone	2, 400
	Unconformity, locally cutting down as low as division 2; no Silurian or Ordovician strata present.		
4	Cambrian	do	600
3	Do	Shale	420
2	Do	Quartzite	800
	Unconformity.		
1	Pre-Cambrian	Tillite and quartzite in Cottonwood quadrangle, also shale and schist farther west (base not exposed).	10, 000±
			14, 220±

On the geologic map (Pl. XXVII) the two limestones, 4 and 5, are shown as merged together south of Little Cottonwood Creek, and a few small areas of pre-Cambrian rocks are merged with the Cambrian quartzite.

The interpretation of the pre-Pennsylvanian stratigraphy that is outlined above differs radically in some respects from that which was offered by the geologists of the Fortieth Parallel Survey.[1] These pioneers believed that the granitic rocks were Archean, and they overlooked the sub-Cambrian and sub-Devonian unconformities. An oversight entailing more serious consequences was their failure to recognize the great overthrust faults that have pushed the Cambrian quartzite on top of Mississippian limestone in both the sections

[1] U. S. Geol. Expl. 40th Par. Rept., vol. 1, pp. 155-172, 1878.

that they chose for special study, that in the canyon of Weber River [1] and that in the Cottonwood region.

The former and present interpretations of the pre-Pennsylvanian section on Cottonwood and Little Cottonwood creeks are as follows:

Stratigraphy of Cottonwood region, according to earlier and later authors.

Fortieth Parallel Survey.	United States Geological Survey.
[Sequence said to be conformable down to base of Cambrian.]	(Sequence in part thrice repeated by overthrust faulting.)
Weber quartzite	Weber quartzite (Pennsylvanian). Unconformity.
Wasatch limestone (mostly Carboniferous but containing Devonian fossils in lower part).	Mississippian (and Devonian?) limestone. Unconformity. Cambrian limestone.
Ogden quartzite (Devonian)	Cambrian shale. Cambrian quartzite. Unconformity. Upper part of pre-Cambrian. Columbus overthrust. Cambrian quartzite. Alta overthrust.
Ute limestone (Silurian)	Mississippian to Cambrian limestone (as above).
Cambrian shale	Cambrian shale.
Cambrian quartzite (12,000 feet thick). Lower Cambrian slates (800 feet thick).	Cambrian quartzite (about 800 feet thick). Unconformity. Pre-Cambrian tillite, quartzite, slate, etc. (about 10,000 feet thick).
Archean granite, limited upward by an extremely rugged erosion surface of pre-Cambrian age.	Granitic rocks are post-Jurassic and form irregular masses cutting all the strata above described.

PRE-CAMBRIAN ROCKS.

One of the classic sections of late pre-Cambrian (Algonkian) strata is exposed along Cottonwood Creek, where their total thickness as measured by Walcott [2] is about 11,000 feet. All the beds below the lowest limestone were classed as Cambrian by the geologists of the Fortieth Parallel Survey and also by Walcott in his earlier paper. In his later paper Walcott regarded as pre-Cambrian all or most of the strata below the fossiliferous Cambrian shale. It is now established that there is an unconformity about 1,000 feet below this shale; and the 10,000 feet, more or less, of strata below the unconformity is regarded as pre-Cambrian.

The general features of the pre-Cambrian are summarized by Blackwelder [3] as follows:

> It consists of alternating beds of quartzite, slate, and conglomerate, which are variable from place to place; cross-bedding, ripple marks, and mud cracks are prevalent. The materials are not well assorted, and in the sandy beds the prevailing colors are yellow, gray, and red, while purple, maroon, and green predominate in the shaly layers. There is apparently a general lack of limestone and of fossils.

The series is regarded by Blackwelder as probably of continental origin.

On Little Cottonwood Creek the pre-Cambrian strata are in great part engulfed or displaced by granodiorite. Schists and quartzites, altered by the intrusion, are exposed near the mouth of the canyon; they may belong to the lower part of the Algonkian or may be Archean. In the western part of the Cottonwood quadrangle about 2,000 feet of pre-Cambrian strata intervene between the base of the Cambrian and the granodiorite. The lower portion of these beds consists mainly of grayish rusty quartzite. The upper portion is regarded by Hintze [4] as tillite, an ancient glacial deposit. Both quartzite and tillite occur in the broad belt of pre-Cambrian rocks in the southwestern part of the quadrangle; the strip farther east, extending south from City Rock Gulch, consists of tillite.

The great outcrops of tillite at the head of Superior Gulch are conspicuously dark and rusty. The bedding of this rock appears distinct in distant views, but the beds are usually thick, the tillite being generally free from lamination and notably tough. Typical blocks consist in greater part of a uniformly dark

[1] Blackwelder, Eliot, op. cit.

[2] Walcott, C. D., The Cambrian faunas of North America, second contribution: U. S. Geol. Survey Bull. 30, p. 38, 1886; Correlation papers—Cambrian: U. S. Geol. Survey Bull. 81, pp. 159, 319, 1891. This measurement can hardly be considered reliable in view of the thrust faults which have been discovered since Walcott's visit and which probably cross this section.

[3] Blackwelder, Eliot, op. cit., p. 524.

[4] Hintze, F. F., jr., op. cit., p. 99.

bluish-green matrix, having the average texture of medium-grained sandstone, in which pebbles and boulders are embedded at wide intervals. Most of the pebbles and boulders are less than 6 inches in diameter; some are well rounded; others are more or less angular. Most of them consist of quartzite, limestone, and other sedimentary rocks, but a few are granitic. The matrix, examined microscopically, shows rounded to angular grains of quartz and feldspar embedded in abundant cloudy mud. The imperfect sorting thus shown by the structure of the matrix as well as by the sparse distribution of the boulders is characteristic of glacial deposits and indicative of glacial origin.

UNCONFORMITY AT BASE OF CAMBRIAN.

An unconformity in the upper part of the great quartzite series of Big Cottonwood Canyon was discovered by Blackwelder [1] in 1909 and was regarded by him as dividing Cambrian from Algonkian strata. A conglomerate lying, at a rough estimate, about 1,500 feet below the top of the quartzites rests here with slight but visible angular discordance upon the beveled edges of lower beds of quartzite and shale. Hintze [2] regards the same unconformity as dividing the tillite of the Cottonwood quadrangle from a persistent conglomerate which forms the base of the overlying quartzite. Although no angular discordance at this horizon has actually been seen within the quadrangle, evidence of unconformity is given by the presence of pebbles of tillite in the conglomerate and by the tapering out of the tillite between the Cottonwood Divide and Cottonwood Creek.

Additional evidence is afforded by comparison of sections in various parts of the Wasatch Mountains. Throughout the range the great body of limestone is underlain by shale, from which in places Cambrian fossils have been taken. Immediately beneath the shale in all known sections there lies a stratum of quartzite, which rests on beds that are mainly siliceous but not wholly quartzitic. The thickness of the series below the Cambrian shale is remarkably uneven. The 11,000-foot section on Cottonwood Creek is the thickest that has been measured in the Wasatch Mountains. At Willard,[3] about 50 miles to the north, only 1,000 to 1,500 feet of quartzite intervene between the Cambrian shale and Archean gneiss; near Santaquin,[4] about 40 miles south of the Cottonwood section, 800 feet of the quartzite rests on gneissoid pre-Cambrian granite containing large inclusions of schist. These variations in thickness may well be due in part to inequalities in the amount of deposition at different places, but considered in the light of the relations observed in the Cottonwood region, they appear to be due in greater part to prolonged and general erosion of gently folded pre-Cambrian strata, followed in early Cambrian time by the deposition of a thick and extensive layer of sand, which now forms the basal member of the Cambrian.

[1] Blackwelder, Eliot, op. cit., pp. 520–523.
[2] Hintze, F. F., jr., op. cit., pp. 96–90.

CAMBRIAN SYSTEM.

Quartzite.—Cambrian quartzite is abundant in the western and southern parts of the quadrangle but is nowhere better exposed than in the hill on the Cottonwood Divide due east of the Monte Cristo mine. Its total thickness at this place is about 800 feet. The basal conglomerate, which is here only 4 feet thick and whose thickness elsewhere in the quadrangle hardly exceeds 10 feet, contains pebbles of quartzite, gneiss, and tillite. The great body of the formation consists of thick-bedded quartzite, which contrasts with the tillite below and the shale above by its bold outcrops and its light though somewhat rusty color. The quartzite is white, pale gray, or pinkish on fresh fracture, hard, vitreous, and rather coarse-grained. Some layers besides the basal one are pebbly, and some are cross-bedded. Between the quartzite and the overlying shale is a transitional zone, about 20 feet thick, of interbedded shale and quartzite.

Shale.—The shaly division of the Cambrian system consists of three well-defined members; the upper and lower members are shales and the middle member is a limestone.

The lower shale is about 240 feet thick. It is fairly uniform in color, unweathered pieces usually being dark gray tinged with bluish green; its outcrops are stained with reddish iron oxide. The uppermost part of this shale is fine grained and fissile, but most of it is

[3] Blackwelder, Eliot, op. cit., p. 520, pl. 36, fig. 2.
[4] Loughlin, G. F., Reconnaissance in the southern Wasatch Mountains, Utah: Jour. Geology, vol. 21, p. 447, 1913.

sandy and rather tough, with wavy and lumpy bedding planes. It is not calcareous with the exception of a few layers which are slightly so. Fossils are numerous, though most of them are poorly preserved. Branching twig-like bodies that may represent some low organism are common in certain beds.

The limestone member, which is about 80 feet thick, is characterized by a peculiar type of lamination. Most of the limestone is fairly massive in appearance and consists in greatest part of blue-gray granular calcite, but it contains thin crinkly layers of a fine-grained siliceous substance which projects in relief on the weathered surface. The siliceous material is most abundant near the top of the limestone stratum, where the thicker layers of it inclose calcareous nodules.

The upper shale is about 100 feet thick. It is lighter and more greenish in original color than the lower, and its weathered outcrops, though even more deeply stained with iron oxide than those of the lower shale, are brownish rather than reddish. Its texture is fine, its bedding planes are smooth, and it is divided into blocks by clean-cut intersecting joints. The upper shale is slightly calcareous and therefore more sensitive to metamorphism than the lower. It contains very few fossils.

Limestone.—The Cambrian limestone of this area is limited at the top by an unconformity. In some places it was wholly removed by erosion before the deposition of the overlying beds; elsewhere as much as 600 feet of it remains. In the neighborhood of the Flagstaff tunnel and at certain places on the top and western slope of Reade and Benson Ridge it is exposed with maximum thickness and minimum alteration, and it is to such exposures that the following description applies.

The Cambrian limestones are in greater part magnesian; they are characterized by various kinds of mottling and lamination and by oolitic and "wormy" structures, and they are interbedded with a little shale and limestone conglomerate. The more peculiar rocks of the series have the following features, which are best observed on weathered surfaces:

"Gray-mottled" limestone: Irregular interpenetrating patches of lighter and darker gray appear on weathered surfaces, the darker patches more gritty than the lighter. Much of this rock is oolitic or "wormy."

Oolitic limestone: Dark-gray spherules, like fish eggs, a millimeter or less in diameter, are thickly crowded in a lighter matrix. These are commonly associated with distinctly larger ellipsoidal bodies about a centimeter in average diameter.

"Wormy" limestone: White bodies, about 2 to 3 millimeters thick and about ten times as long, either roughly cylindrical, branching, or irregular in shape, are embedded in a darker matrix.

Buff-mottled limestone and shale: The nature of the buff-mottled rock is similar to that of the limestone interbedded with the shale below. It is made up of two materials, blue-gray nonmagnesian limestone and calcareous but also more or less siliceous material which has a buff color and stands in relief on weathered surfaces. Every gradation may be observed between blue limestone slightly mottled or banded with buff, buff rock containing thin lenses and flat nodules of blue limestone, shale containing rounder nodules, and fissile, buff-stained olive-green shale that is free from nodules.

Limestone conglomerate: Several thin beds of intraformational limestone conglomerate are associated with the buff-mottled limestone. The pebbles are flat, consist exclusively of limestone, and are embedded in a limestone matrix.

The following section is compiled from exposures between the Cardiff and Flagstaff mines. The thicknesses given are approximate.

Composite section of Cambrian limestones.

	Feet.
8. Magnesian limestone, gritty surfaced, dark to light gray, gray mottled, and oolitic	70
7. Shale and partly flaggy buff-mottled limestone, shale dominating near top and bottom	150
6. Dark buff-mottled limestone, the buff material generally subordinate; some gray-mottled layers	75
5. Magnesian limestone, mostly dark and gray mottled, with oolitic and "wormy" layers. (A thin bed of limestone conglomerate near the top of this division and several others in divisions 6 and 7).	75
4. Fine-grained limestone; lower half cream-white and finely fluted on weathered surface; upper half yellowish, in part sandy, and strongly fluted.	30
3. Magnesian limestone, nearly black, crowded with conspicuous white "worms," alternating with thinner light-gray bands; called "guinea-hen" limestone in the field	20

	Feet.
2. Magnesian limestone, rather thick bedded, sharply jointed, mostly dirty light gray and unmottled but containing some coarsely mottled layers and some "wormy" layers like division 3.	60
1. Magnesian limestones, generally dark blue-gray and thin bedded; gray mottling with some tinges of buff is common; many layers are oolitic and some are "wormy"; sandy laminae in lowest 10 feet	105
Cambrian shale.	
	590

The most useful horizon markers in the formation are the white stratum (division 4) and the shaly beds and associated buff-mottled limestone (division 7). The white stratum is conspicuous on the slope west of the Flagstaff tunnel, and on the west slope of Reade and Benson Ridge its occurrence in several parallel bands with nearly uniform easterly dip is the most clearly visible evidence of the repeated thrust faulting that has there taken place. The shale and buff-mottled limestone, though less prominent, are even more distinctive, and their contrast to the other beds is not diminished by metamorphism, which obscures or obliterates the peculiarities of most of the other sorts of Cambrian limestone. (See p. 242.)

Fossils and correlation of Cambrian rocks.—Abundant fossils collected by Messrs. Butler and Loughlin from the lowest member of the Cambrian shale have been identified by Edwin Kirk as Middle Cambrian. Walcott[1] reports the Lower Cambrian fossils *Olenellus gilberti* and *Cruziana sp.* from a narrow zone at the base of this shale on Big Cottonwood Canyon, as well as Middle Cambrian fossils about 100 feet higher; but Lower Cambrian fossils were not found in the recent examination of the region. The quartzite below the shale has yielded no fossils in this region, but its Cambrian age is fairly evident from its gradation to the overlying shale and its unconformity with the underlying strata.

A few fossils taken from the upper member of the shale formation and from the base of the limestone are regarded by Messrs. Walcott and Kirk as possibly Upper Cambrian. Some of the highest beds of shale associated with the buff-mottled limestone (division 7, p. 236) have yielded two brachiopods and a trilobite which, according to E. O. Ulrich, indicate a horizon rather low in the Upper Cambrian. It has not been proved that the gray-mottled beds above this shale are Cambrian, but their resemblance to lower beds that are certainly Cambrian may justify a provisional assignment to that system.

The peculiar oolitic, "wormy," and mottled structures are perfectly duplicated in the Cambrian limestones of Montana and other regions. The general ascending sequence—quartzite, shale, limestone—is characteristic of the Cambrian in the American Rockies, and there is a striking resemblance in many respects between the Cottonwood section and the section at Philipsburg, Mont.[2]

UNCONFORMITY AT BASE OF DEVONIAN OR CARBONIFEROUS LIMESTONE.

The base of the limestone series above the Cambrian is marked by an unconformity, the evidence of which is best observed on the west slope of Reade and Benson Ridge. At a point 1,100 feet northeast of the Kennebec tunnel, a pebbly sandstone lies with a discordance in dip of about 5° upon ocherous limestone, limestone conglomerate, and shale belonging to the upper part of division 7 of the Cambrian limestone. (See p. 236.) The beds above and below the unconformity diverge toward the south, and in that direction the uppermost gray-mottled limestone of the Cambrian soon appears and gradually thickens.

These relations give the clue to the great differences in the thickness of the Cambrian limestone at different places. At a point 100 yards northwest of the locality described above, but separated from it by an overthrust, the unconformity lies on the gray-mottled stratum (division 4) below the main buff-mottled beds. On Montreal Hill, across Mill D South Fork, it lies near the base of the Cambrian limestone, the thin remnant of which is not distinguished on the map. The juxtaposition of limestone with Cambrian quartzite at the mouth of Days Fork is probably due to this unconformity. In the vicinity of Mill D South Fork, therefore, the amount of erosion increased westward and northward; if, therefore, the old erosion surface was nearly plane, the Cambrian rocks in

[1] Walcott, C. D., Correlation papers—Cambrian: U. S. Geol. Survey Bull. 81, p. 319, 1891.

[2] Emmons, W. H., and Calkins, F. C., Geology and ore deposits of the Philipsburg quadrangle, Mont.: U. S. Geol. Survey Prof. Paper 78, pp. 49-64, 1913; U. S. Geol. Survey, Geol. Atlas, Philipsburg folio (No. 196), 1915.

this part of the quadrangle were tilted southeastward before the period of erosion.

Southeast of the Bodfish tunnel on Silver Fork the buff-mottled limestone and an unknown thickness of rock below it are cut away by the unconformity.

In passing along the south slope of the Cottonwood Divide, from Superior Gulch, one finds an abrupt change in the level of the unconformity on crossing each major fault. In the cliffs just east of Superior Gulch the unconformity lies below the buff-mottled limestone (division 6). North of Alta it lies on the uppermost gray-mottled Cambrian limestone. At the Alta Consolidated mine, on the contrary, the Cambrian limestone is entirely absent, the highest Cambrian bed belonging to the upper member of the shale. On Honeycomb Hill, again, the buff-mottled limestone and shale (division 7) and a little of the uppermost gray limestone are present.

As already indicated, the boundaries between the Cambrian and the later limestone have not been traced south of Little Cottonwood Creek, and the fact that the map fails to show a distinctive color for Cambrian limestone in the southern part of the area therefore does not mean that the unconformity here lies on the Cambrian shale.

DEVONIAN (?) AND CARBONIFEROUS LIMESTONE.

Distribution and character.—The strata that occupy the interval of nearly 2,400 feet between the post-Cambrian unconformity and the Weber quartzite occur chiefly in a broad zone extending from the northwest to the southeast corner of the quadrangle, and they form the country rock of some valuable ore bodies. They consist predominantly of limestone but comprise a little shale and sandstone near the base and a well-defined member, about 300 feet thick, consisting chiefly of the same rocks not far below the top. The limestones bear none of the peculiar markings that are characteristic of the Cambrian limestones. In greater part they are nonmagnesian, prevailingly dark blue-gray, though varying almost from black to white, and more or less cherty and fossiliferous; but the lower strata contain little chert and few fossils, and some of them are magnesian. The chert forms lenses, pods, and irregular lumps, quite unlike the thin layers of siliceous material in some of the Cambrian limestones.

The stratigraphy of these post-Cambrian limestones has been less carefully worked out than that of the Cambrian limestones. Some of the measures of thickness given in the following section are averages from several rough measurements, whose differences, though probably due in part to errors and to undetected faulting, must in part represent actual variations in the thicknesses of the strata.

Generalized section of Mississippian (and Devonian?) limestones.

	Feet.
Unconformity (?) at base of Weber quartzite.	
11. Limestone, blue to white	350+
10. Sandstone, calcareous, buff weathering, commonly brecciated, interbedded with limestone and overlain by about 35 feet of reddish shale.	285
9. Limestone, dark blue to white, containing little chert, interbedded with one or two layers of sandstone near the top	400−
8. Very cherty limestone, dark blue gray; conspicuous coral beds in upper part	250+
7. Whitish crinoided limestone containing large lumps of pale-tinted chert near the base	10–120
6. Very cherty limestone, dark blue; thin beds of black shale near base	300
5. Limestone, less cherty, proportion of chert decreasing downward, blue-gray	450
4. Conspicuous bed of bluish-white, pure, brittle, fine-grained limestone	15
3. Limestone, dark blue-gray to light blue-gray or white, slightly magnesian in part, thick-bedded above, thinner bedded below; basal part (20 feet ±) is flaggy and rusty and contains abundant vugs	80
2. Massive, whitish, somewhat magnesian limestone, containing a few vugs	50
1. Thin-bedded impure vuggy limestone, mostly greenish gray, locally interbedded with dark gray shale and underlain by pebbly sandstone	20±
Unconformity.	
Cambrian rocks.	2,210–2,320

The divisions most useful as horizon markers are probably 1, 2, 4, and 7.

The character of division 1 is very distinctive at the locality northeast of the Kennebec tunnel (see p. 237), where it includes a basal bed of pebbly sandstone and some layers of dark shale. The pebbly bed is present north of Cottonwood Creek but is absent in most of the other sections observed. Near Alta this division is best recognized by its thin bedding, by the presence of crystal-lined cavities or vugs, and by its relation to division 2.

Division 2 is unique in its combination of light color and massive, homogeneous char-

acter which form a contrast with the gray flaggy beds both below and above.

Division 4, a thin bed conspicuous for its light color, has sometimes been confused with division 4 of the Cambrian limestone (see p. 236) and is similarly useful in the working out of the structure of the northwestern part of the quadrangle. East and south of Alta its whitish color is less distinctive because the dark limestones are there so largely bleached by contact-metamorphic agency, the dark colors mentioned in the table being those of the unaltered limestones.

Division 7 is in most places the thickest light-colored bed that lies well up in the series, but it shows marked variation in thickness, being 120 feet thick on the north side of the Cottonwood Divide, and hardly 10 feet thick in some places on the south side.

Age and correlation.—Hintze [1] draws from the study of numerous fossils collected by him the conclusion that more than 1,000 feet of the great post-Cambrian limestone is of Devonian age. On the other hand, G. H. Girty [2] considers that the fossils collected by B. S. Butler from the limestone below the sandstone (mainly within 500 feet of the base) are of lower Mississippian (Madison) age. It may be assumed, provisionally, that both Devonian and Madison limestones are present, but further field study will be necessary to locate the boundary between them. The shaly beds that in some places immediately overlie division 2 (see p. 236) suggest a discontinuity of sedimentation and possibly mark the base of the Madison.

The fossils in the limestone (division 11) above the sandstone indicate an upper Mississippian (Brazer) age. The sandstone itself is barren of fossils but is thought to be of lower Brazer age. It probably is the equivalent of a shale formation found by Blackwelder [3] in the Ogden region. According to Blackwelder, this formation is unconformable with the underlying limestone and grades into another limestone that overlies it.

[1] Hintze, F. F., jr., A contribution to the geology of the Wasatch Mountains, Utah: New York Acad. Sci. Annals, vol. 23, pp. 108-113, 1913.

[2] Personal communication.

[3] Blackwelder, Eliot, New light on the geology of the Wasatch Mountains: Geol. Soc. America Bull., vol. 21, p. 528, 1910.

IGNEOUS ROCKS.

STOCKS.

General relations.—The igneous rocks of the Cottonwood-American Fork area are all intrusive. Two of the intrusive masses that lie on the prolongation of the Uinta axis are exposed within the Cottonwood quadrangle. At the west is the Little Cottonwood stock of granodiorite, which extends to the front of the range, and at the east, extending from Alta into the Park City district, is the composite Alta-Clayton Peak stock of granodiorite and quartz diorite. Although there is no surface connection between these two stocks, they are probably connected beneath the surface and were certainly derived from a common magma. They are closely related in composition. The Little Cottonwood stock is the most siliceous, the granodiorite east of Alta is slightly less so, and the quartz diorite, which lies farthest east, is the least siliceous.

The intrusive relation of the Alta-Clayton Peak stock to the sedimentary formations is proved by the general truncation of the bedding along the contact, by the projection of narrow tongues or apophyses of igneous rock from the main body into the sediments, and by striking phenomena of contact metamorphism. The Little Cottonwood stock is less plainly intrusive, but close examination of its contact shows that this mass also sent out apophyses and produced metamorphic effects. Both stocks, however, were regarded by the geologists of the Fortieth Parallel Survey as Archean. Their intrusive nature was argued first by Geikie in 1880 [4] and some years later by Van Hise.[5] It was subsequently verified by Boutwell and by Emmons,[6] who revisited the district in 1902.

Little Cottonwood stock.—The Little Cottonwood stock consists of siliceous granodiorite. A specimen obtained on Little Cottonwood Creek a third of a mile below the power house is typical of a great part of the mass and has been chemically analyzed. (See p. 95.) It is

[4] Geikie, Archibald, Archean rocks of the Wahsatch Mountains: Am. Jour. Sci., 3d ser., vol. 19, pp. 363-367, 1880.

[5] Van Hise, C. R., Correlation papers—Archean and Algonkian: U. S. Geol. Survey Bull. 86, pp. 204, 297-298, 1892.

[6] Emmons, S. F., The Little Cottonwood granite body of the Wahsatch Mountains: Am. Jour. Sci., 4th ser., vol. 16, pp. 139-147, 1903.

light gray and medium grained. Its predominant minerals are quartz, pure-white plagioclase, and more transparent, slightly pinkish orthoclase. Quartz and orthoclase are each about half as abundant as plagioclase. Biotite and hornblende in small, nearly equal quantities form black irregular particles; and small yellowish-brown crystals of titanite are numerous. The plagioclase, as determined microscopically, is a calcic oligoclase near $Ab_{75}An_{25}$. A slight porphyritic tendency is shown by the orthoclase, which forms crystals as much as a centimeter long, fairly idiomorphic though full of inclusions. In other parts of the mass, as in Gad Valley, near the southwest corner of the quadrangle, the rock is distinctly and coarsely porphyritic, some phenocrysts of potash feldspar being more than an inch in length.

Dark inclusions, commonly a few inches in diameter, composed of the same minerals as the dominant rock but containing a greater proportion of plagioclase, biotite, hornblende, and accessories, are abundant and conspicuous in the Little Cottonwood stock. They are regarded as representing material which crystallized against the walls of the stock at an early period and was subsequently broken up and scattered through the magma.

Alta-Clayton Peak stock.—The Alta-Clayton Peak stock is composed of two parts that differ considerably in appearance but only slightly in composition. The western part, near Alta, consists of a moderately coarse-grained light-colored granodiorite; the eastern part, surrounding Clayton Peak, consists of quartz diorite that is distinctly darker and finer.[1] The boundary between these rocks extends from a spur of Pioneer Peak, in the southeastern part of the Cottonwood quadrangle, to the head of Thaynes Canyon, near the western limit of the Park City quadrangle. A small isolated area of diorite lies north of Mount Evergreen, and there are two others near the head of Snake Creek.

The relation of the diorite to the granodiorite is not entirely clear. A suggestion that the diorite is the older is given by the presence of inclusions resembling it in the granodiorite at some places, as near the pass between Alta and Brighton. Along the greater part of their contact the transition from the one rock to the other is rather abrupt, the distance between outcrops of normal diorite and of normal granodiorite being at most a few hundred feet and in places only a few yards. But where this contact approaches the northern boundary of the stock the transition is gradual, and no sharp line of demarcation is found, although the exposures are excellent.

These somewhat ambiguous facts appear to be reconciled by supposing that the two rocks were derived from a common magma; that the diorite is the material that solidified first, before much differentiation had taken place; and that when solidification was still far from complete the magma was disturbed by crustal movement, and liquid which had undergone some differentiation and which possessed the composition of granodiorite was generally brought into contact with the diorite that had already congealed. In the embayment at the north, where the transition is gradual, the magma was sheltered from the movement produced in the main body of the stock.

The granodiorite east of Alta is a light-gray rock, only a little darker than that of the Little Cottonwood stock. Its texture is granular and medium grained. In a fresh hand specimen the plagioclase, quartz, and orthoclase, which make up the bulk of the rock, are translucent grayish white and are not easily distinguished from one another. Blackish hornblende and biotite are noticeably more abundant and more perfect in crystal form than they are in the Little Cottonwood stock; the hornblende is especially prominent, forming many prisms as much as 5 millimeters in length, while the diameter of most of the biotite crystals is less than 2 millimeters. Small grains of titanite are common though inconspicuous. The microscope shows that the plagioclase has an average composition near that of oligoclase andesine ($Ab_{70}An_{30}$) and that the orthoclase, which occurs interstitially, is less than half as abundant as plagioclase.

A description of the diorite, which occurs mainly in the Park City quadrangle, is given in the account of that district. (See p. 296.)

[1] These two rocks were discriminated and the general course of the boundary was traced by Boutwell (op. cit., p. 65), but the granodiorite was not delimited on his map nor specially described in his report, because of its insignificant extent and its gradation to diorite within the Park City quadrangle.

DIKES.

Classification.—The dikes of the area, only the more important of which are shown on the map (Pl. XXVII), comprise (1) porphyry resembling granodiorite in composition, (2) a more siliceous soda granite porphyry, (3) dark lamprophyric rocks rich in hornblende or biotite, and (4) aplite and pegmatite. The dikes of the first class represent undifferentiated or slightly differentiated magma from the large irruptive masses, injected into fissures leading from the magma chamber; the others are doubtless derived from the same magma by differentiation. The most usual trend of all these dikes is easterly or northeasterly, though some of them strike nearly due north.

Granodiorite porphyry.—Gradation from normal granodiorite to fine-grained porphyry may be traced in a dike that branches from the main mass near the head of City Rock Gulch and extends northeastward toward the Black Bess shaft. The texture becomes finer and more distinctly porphyritic and the color becomes darker as the width of the dike and the distance from the main body diminish. This observed gradation makes it fairly certain that many other dikes of porphyry, varying from granodiorite toward monzonite on the one hand or diorite on the other, are offshoots from the large intrusive bodies, even though the connection is usually concealed. Such dikes occur in many places, especially in the vicinity of the granodiorite, one of the most remote being the Tar Baby dike, which crosses Reade and Benson Ridge a mile and a half from the Cottonwood Divide. They are also to be seen in the vicinity of the Maxwell mine, outside of the Cottonwood quadrangle.

The dikes of this class bear phenocrysts of plagioclase, hornblende, and biotite in a groundmass consisting of the same minerals together with orthoclase and quartz. In one or more of the dikes near the east end of the Cottonwood Divide there are remarkably abundant inclusions of sedimentary rock.

Soda granite porphyry.—A white porphyry of very uniform character is found at many places on the north side of Little Cottonwood Canyon, from the Frederick tunnel to the Honeycomb Cliffs. The rock consists mainly of a grayish-white extremely fine grained groundmass, in which are embedded a few small phenocrysts of white feldspar and of dark-looking quartz. The feldspar phenocrysts are albite; the groundmass consists of albite, quartz, and perhaps a little orthoclase. No ferromagnesian minerals are present. The freshest specimens obtainable are much decomposed.

A prominent dike of this rock occurs near the top of the knoll just north of the Columbus Consolidated plant and is penetrated by the Tom Moore tunnel of the Columbus workings. Another, or possibly a continuation of the same dike, crops out near the Grizzly tunnel at the head of City Rock Gulch. Several dikes of white porphyry are exposed in the Honeycomb Cliffs, where one of them cuts diagonally across a dike of diorite porphyry.

Lamprophyres.—Fine-grained nearly black dikes have been found in some places but are not common. A group of narrow parallel dikes injected in a fissure zone east of Superior Gulch consists of a rock that is rich in biotite and is probably minette or kersantite, the feldspar being so thoroughly decomposed that a closer identification is impossible. A rock resembling fine-grained basalt occurs northwest of the Prince of Wales shaft. The microscope shows that it once contained phenocrysts, probably of olivine, which are now completely replaced by carbonate and a micaceous mineral. The groundmass that makes up most of the rock is a feltlike mixture of hornblende and feldspar laths. The rock may be classed provisionally as a camptonite.

Aplite and pegmatite.—In the stocks of granodiorite, as in such bodies generally, aplitic dikes are numerous and a few of pegmatite were noted, but such dikes are not common in the sedimentary rocks at a distance from the large intrusive bodies, and none of them appear to require especial notice except one or two that are of unusual character.

One of these is an aplite that forms a prominent outcrop on the ridge west of Lake Solitude. This rock is pale greenish gray; its texture is aplitic, but it contains many little vugs. It has two essential constituents, the more abundant of which is white and the other apple-green and which prove, on microscopic examination, to be scapolite and monoclinic pyroxene, respectively. Quartz is wholly lacking, and no feldspar is present except a very little orthoclase. Titanite, apatite, and zircon are

notably abundant accessories. The rock is similar to some that occur in the Philipsburg district, Mont., though the Montana rocks contain abundant feldspar.[1] A pyroxene-scapolite dike rock without feldspar, occurring in California, is described by Harder.[2] The scapolite in these and in the Cottonwood rock is regarded as primary.

Associated with an amphibole-bearing aplite that occurs in diorite northwest of the pass between Silver Lake and Snake Creek is a coarsely crystalline vein consisting of quartz and dark-green pyroxene that is partly altered to fibrous amphibole. This vein, though small, is of interest as being presumably a product, within the intrusive mass, of solutions which were expelled from the magma in the later stages of its solidification and which reacted upon the adjoining limestones to form pyroxene and other silicates.

CONTACT METAMORPHISM.

The contact metamorphism produced by the Little Cottonwood stock has been exerted mainly on siliceous rocks, which do not show its effects very plainly. It extends, however, to the southern part of the westernmost band of limestone. The metamorphism apparent in the limestone cliff just east of Superior Gulch is due, at least in part, to this intrusion, though it may also be due partly to the Alta-Clayton Peak stock, for the contact zones of the two stocks apparently coalesce in Little Cottonwood Canyon. The metamorphic effects of the Alta-Clayton Peak stock, which is surrounded mainly by limestones, are far more striking than those of the Little Cottonwood stock. They extend northward on Silver Fork at least a mile from the visible contact, and have been traced about as far beyond the southern boundary of the stock at the head of Snake Creek.

The sedimentary rocks in the contact zone include all sorts from quartzite to pure limestone. Near the intrusive rocks the purer quartzites are more vitreous than elsewhere and the less pure quartzites and the siliceous shales glisten with mica and are in places dappled. Dappled hornstones derived from Cambrian shale in City Rock Gulch are found microscopically to consist of a mosaic of quartz, orthoclase, and biotite, inclosing aggregates of mica that probably represent altered andalusite or cordierite or both. The shales are garnetized in places close to the intrusive contact. The most striking effects of contact metamorphism are shown by the limestones and are best observed around the Alta-Clayton Peak stock. Some of them do not prove the combination of magmatic with sedimentary material, but others clearly do involve such combination.

The most widespread effects of metamorphism on the limestones are coarsening of texture and bleaching. The bleaching is most strikingly displayed on the cliff east of Superior Gulch and on the west slope of the Prince of Wales Hill. The limestones at both these places display a certain amount of original banding, but they are also blotched with great irregular patches and streaks of white whose boundaries cut across the stratification; and some white streaks of uneven width extend along fissures, which clearly afforded passage to the vapors or liquids that effected the bleaching.

An effect that extends almost as far as bleaching and that constitutes more definite proof of metamorphism is the development of the lime-magnesia silicate tremolite. This mineral, which is easily recognized by its splintery form, white or gray color, and silky luster, is common in the Carboniferous limestones and is found as much as a mile from any outcrop of granular intrusive rock. It forms most abundantly around nodules of chert and in beds of sandy limestone, an association which indicates that the silica contained by the tremolite is at least in part of local origin; and the magnesia, too, may have been derived from the limestone, though tremolite abounds in beds that are not visibly magnesian.

Tremolite occurs in the magnesian limestones of the Cambrian system, but forsterite, a lime-free silicate of magnesia, is more characteristic of these rocks, though it does not occur so far from intrusive contacts. It is best perceived on the weathered surface, where it has a yellow discoloration. The presence of forsterite in the Cambrian and its absence from the Carboniferous limestone gives much help in tracing the obscure Michigan-Utah overthrust along the west slope of Honeycomb Hill. The forsterite occurs so abundantly in beds that

[1] Emmons, W. H., and Calkins, F. C., Geology and ore deposits of the Philipsburg quadrangle, Mont.: U. S. Geol. Survey Prof. Paper 78, p. 120, 1913.

[2] Harder, E. C., Iron-ore deposits of the Eagle Mountains, Cal.: U. S. Geol. Survey Bull. 503, p. 53, 1912.

originally were nonsiliceous that it probably contains magmatic silica. Abundant pellets of brucite ($Mg(OH)_2$) occur in some of the limestone that contains forsterite. The forsterite, however, is altering to serpentine, while the mineral from which the brucite is derived is represented by residual grains, inclosed in many of these pellets, of an isotropic strongly refracting mineral which is probably periclase (MgO).[1]

In the alteration of the banded, buff-mottled limestone of the Cambrian (division 7, p. 236) for some rods from the contact on Honeycomb Hill, the dominant effect has been a combination of the lime with the silica and other matter in the buff layers, which are represented in the altered rock by a coarsely crystalline mixture of reddish garnet and greenish vesuvianite with a little inconspicuous pyroxene. These resistant silicates project from the weathered surface in rough lumps and ridges.

Elsewhere hard masses of silicates and other minerals, mixed with residual calcite, are formed from nearly pure limestone. Near the head of City Rock Gulch the Carboniferous limestone is almost wholly converted to garnet, pyroxene, and other silicates for at least 15 feet from the contact, and the replacement extends much farther than this along certain beds, which are not siliceous. It is clear that large amounts of silica, iron, and probably magnesia and other substances carried outward from the magma in hot, perhaps gaseous solution have combined with the lime of the sedimentary rock. The alteration has affected the walls of certain fissures through which these emanations moved. It is even more evident that the thick sheets of garnet rock which border dikes a few feet or even a few inches thick on the slopes both north and south of City Rock Gulch could not have been formed by the action of the dikes themselves, for thicker dikes near by exerted no visible effect on their walls; these sheets were clearly produced by emanations that issued from the main intrusive body through the fissures into which the dikes were injected. Especially intense metamorphism is observed also along the contact south of Dog Lake, where the diorite is cut by unusually numerous dikes of aplite and pegmatite, and it is probable that the fissures occupied by these dikes served as channels for solutions expelled by the magma.

[1] Cf. Rogers, A. F., American occurrence of periclase and its bearing on the origin and history of calcite-brucite rocks: Am. Jour. Sci., 4th ser., vol. 46, pp. 581-586, 1918.

The silicate minerals that are most abundant in these massive contact rocks are garnet, monoclinic pyroxene, vesuvianite, forsterite, epidote, and micas; scapolite is found but does not seem to be common. The oxides spinel and magnetite are abundant in places. Magnetite occurs in the South Hecla mine; it is conspicuous along the contact south of Dog Lake; it crops out on the Michigan-Utah property near the Brighton trail; and a large mass of it is penetrated by the workings of the Alta Consolidated and Michigan-Utah mines. The rare magnesium-iron borate ludwigite occurs near Dog Lake, where it is associated with magnetite and forsterite, and also near the head of City Rock Gulch and in the South Columbus tunnel. Sulphides of iron and copper are among the contact minerals in places, and the presence of copper is often betrayed by a green stain. Some contact rock rich in magnetite is even mined for copper. The presence of magnetite, of ludwigite, and of sulphides is especially strong evidence of accession of material from the magma, for the sediments clearly did not contain enough iron, boron, or sulphur to form these minerals.

STRUCTURE.

PRELIMINARY OUTLINE.

The main lineaments of the geologic map of the Cottonwood quadrangle, which appears almost chaotic at first glance, are determined by a comparatively small number of major structural features.

The fundamental structure, affecting the whole body of stratified rock, is the northeastward-pitching Park City anticline, whose axis passes through the center of the quadrangle. The expression of this fold, if it were unmodified and the surface were flat, would be an arrangement of the formations as concentric bands of northeastward convexity in sequence of decreasing age from southwest to northeast. A tendency to such arrangement is still visible but is greatly obscured by intrusion and faulting.

The most conspicuous interruption of the bands is caused by the Little Cottonwood and Alta-Clayton Peak intrusive stocks.

Other striking modifications are caused by a few great faults. The greatest of these is the Silver Fork fault, a north-south fracture of low west dip extending through the center of the quadrangle and causing a downthrow of at least

2,000 feet on the west side. Two faults of similar direction but steeper and causing a downthrow to the east extend northward from Superior Gulch. Another fault of the first magnitude runs northwestward along Cottonwood Creek and has caused a downthrow of about 2,000 feet on the southwest side.

Dislocations even greater than those described have been effected by a series of overthrusts that lie for the most part nearly parallel to the planes of stratification and for this reason are less conspicuous than the other great faults which cut the beds at fairly large angles almost throughout their course. The chief effect of these overthrusts on the areal distribution of the rocks has been to duplicate or to broaden the outcrops of the Cambrian formations. By far the greatest is the westernmost, which enters the area mapped near the Carbonate mine and probably extends to Mineral Flat. Some higher overthrusts that cross the creek near Alta are thought to have been brought to the surface again on the east side of the Silver Fork fault.

The details of the pattern whose outlines have been sketched are formed in very small part by minor folds but mainly by a great number of faults whose throw is measurable in tens or hundreds rather than in thousands of feet. Most of these relatively minor faults are steep in dip, but only a part of them are normal, many of them being reversed. Many of the minor faults are still unmapped, the traces of many having been lost in large areas of homogeneous rock and others being neglected, for the present at least, because of their very small throw. Among these last are the mineral-bearing fissures, which, though structurally unimportant, are preeminent in practical interest.

The many obscurities involving the character and relation of the minor faults form one of the chief obstacles to a thoroughly systematic grouping of the structural features. The groups that will be set up for the purposes of the following description include (1) the folds, (2) the overthrust faults, (3) the other mapped faults, including normal faults and steep reversed faults, and (4) the mineralized fissures. After the principal features of each group have been described, the genetic relations of the folds, faults, and fissures to one another, to the igneous intrusions, and to the broad structure of the Wasatch and Uinta ranges will be briefly considered.

FOLDS

Park City anticline.

The structural feature that has the greatest effect on the distribution of the rocks throughout the Cottonwood-Park City region is the Park City anticline, a westward continuation of the Uinta anticline. The crest of this great arch runs nearly level along the main body of the Uinta Range, dips downward between that range and the Wasatch, pitches strongly eastward through its course across the Wasatch, and is cut off by the great normal fault whose footwall, degraded and dissected by erosion, forms the western face of the range.

Throughout the Wasatch Range the fold is much defaced by intrusion and by faulting. The reader who views the Cottonwood map (Pl. XXVII) with his attention abstracted from these features will see that the sedimentary formations tend to form concentric bands, whose curvature is sharpest along the line of Little Cottonwood Canyon and is convex northeastward. The strata are observed in the field to dip, in general, northward, northeastward, and eastward. The dip ranges in steepness from vertical to horizontal. Near Alta it is usually not far from 35°; gentler dips are common to the east and north; steeper dips prevail to the west and south.

Other folds.

The only other fold that is large enough to be clearly expressed on the map is an open eastward-pitching syncline that flanks the Park City anticline on the south. This fold is outlined by the band of Cambrian shale west of the Devils Castle. It is not comparable in magnitude to the Park City anticline, being inconspicuous on the geologic map of the State. (See Pl. III, p. 69.)

Some crumpling is associated with and clearly incidental to the overthrust faulting. It is especially well developed in the Cambrian shale between the Alta and Columbus overthrusts and in the shale under the Alta overthrust on Carbonate Peak. Minor folding apparently unconnected with thrusting is conspicuous in the rusty pre-Cambrian rocks west of Superior Gulch. Its character is indicated in structure section A–A′, Plate

XXVII. Its principal elements are a syncline and an anticline leaning over toward the east; they indicate the agency of an overriding pressure from the west that would, if continued until the strata broke, result in an overthrust of westward dip. Similar folding, less well developed, is shown in the quartzite north of the Columbus mine.

Small folds that are still more strongly recumbent toward the northeast are well exposed on the hill that lies across Silver Fork from the Prince of Wales shaft. Several small folds of easterly strike are developed in the limestones of Honeycomb Hill and are clearly exposed in the Honeycomb Cliffs.

OVERTHRUST FAULTS.

General features.

The reversed faults here classed as overthrusts are only those that have the usual low dips, the discussion of steep reversed faults being reserved for another section. The overthrusts of low dip that have been found in the Cottonwood quadrangle strike about north and dip, on the average, about 30° E., but their dip is not uniform and they appear to have been affected by later folding. In general they are rudely parallel to the tilted sedimentary strata, though they locally cut the beds at all angles up to 90°. They are older than the intrusive rocks and older than most of the other faults.

The overthrusts that have been traced are, in east-west order, the Alta overthrust, the Columbus overthrust, the Reade and Benson thrust zone, and the Grizzly thrust zone; the last two may be equivalent to each other. All these are cut by structure section A–A′, Plate XXVII (in pocket).

Alta overthrust.

The westernmost and greatest of the thrust faults was discovered independently in 1912 by Loughlin[1] and by Hintze[2] and was named by Hintze the Alta overthrust. It is best exposed on the steep slope east of Superior Gulch. The lowest part of this slope is Cambrian quartzite, which is overlain by shales and by limestones whose upper beds contain Mississippian fossils. Upon the limestones and nearly conformable to them in dip (about 30° E.) lies a second thick stratum of quartzite, which the geologists of the Fortieth Parallel Survey called the "Ogden quartzite" and regarded as of Devonian age. This quartzite, however, is Cambrian, and is thrust over the Mississippian limestone, from which it is separated through part of its extent by a crumpled wedge of Cambrian shale. The fissures that bound the wedge of shale are two branches of the Alta overthrust, the movement on which amounted certainly to thousands of feet and perhaps to several miles. The movement was confined for long distances to what is virtually a single fissure, but two main branches are present in the workings of the Cardiff and Columbus-Rexall mines and on the surface near the heads of Superior Gulch and Mill D South Fork. (See Pl. XXIV, p. 207.)

The Alta overthrust has been traced southward to Mineral Flat, where its identity is lost in a complex of block faults; probably, however, it extends much farther south. A short distance north of Little Cottonwood Creek it is cut off by the east branch of the Superior fault; the fault-bounded triangular area of Cambrian shale and quartzite northwest of the Cardiff mine may represent a piece of the overriding block, and the second fault south of the Carbonate mine is probably the continuation of the Alta overthrust. Where this fault reaches the crest near the Carbonate mine the contact of the flat-dipping quartzite with the overridden, steeply dipping crumpled shale is visible at a great distance. The overthrust has not been traced beyond this crest, but it probably extends much farther and may well cause an apparent thickening of the Algonkian strata on Cottonwood Creek.

Columbus overthrust.

The next overthrust east of the Alta crosses Cottonwood Creek near the mouth of the Columbus tunnel and therefore may be called the Columbus overthrust. This fault probably has far less throw than the Alta overthrust, but it virtually duplicates the Cambrian quartzite on the Cottonwood Divide. Its dip is 30° NE. where it crosses the gulch northwest of the Columbus tunnel. The Cambrian shale beneath it on the slope is very strongly crumpled. At the head of Mill D South Fork its best exposure shows it steep-

[1] Loughlin, G. F., Reconnaissance in the Wasatch Mountains, Utah: Jour. Geology, vol. 21, pp. 439–443, 1913.
[2] Hintze, F. F., jr., op. cit., p. 133.

ening downward, with an average dip of 65° E.; here it is parallel to the bedding and is attended with no local crumpling and little brecciation.

The Columbus overthrust is thrown down to the west by a small fault that crosses the Cottonwood Divide. West of this later fault the thrust plane has a low dip and for the most part is nearly parallel to the bedding above and below; but by a favorable light sharp folding may be seen in the overridden quartzite. The overthrust is probably cut off by the east Superior fault, beyond which it has not yet been picked up. It has not been traced far south of Little Cottonwood Creek.

Reade and Benson thrust zone.

All the overthrusts that have been mapped between the Columbus and Grizzly faults are confined to a rather narrow strip that will be called the Reade and Benson thrust zone. The portion of this zone that has been studied with any degree of thoroughness may be described roughly as the main belt of Cambrian shale and limestone between Alta and Montreal Spring. South of Little Cottonwood Creek, where the Cambrian limestone has not been separated, the thrust zone has not been followed, though it probably persists as far as the Silver Fork fault. At the north it certainly extends into the cliffs of Devonian and Carboniferous limestone northeast of Montreal Spring and is known to account in part for their intricate structure; but faults are traced less readily in this great mass of relatively homogeneous rock than in the strongly differentiated strata of the Cambrian system.

Favorable stratigraphic position and excellent exposures make the evidence of this overthrusting especially clear in the Cambrian rocks that extend along the west slope of Reade and Benson Ridge. Here the greater faults bring Cambrian shale over limestone, or Cambrian over post-Cambrian limestone; the lesser ones thicken the limestone or the shale, as is proved by the repetition of distinctive beds. The overthrusting has not been accompanied, as a rule, by much brecciation or crumpling; but the displacement must have amounted to many hundreds of feet on some of the overthrusts, and the easternmost is more than a mile in length.

At the south end of Reade and Benson Ridge the exposures are less good and the structure has minor complexities that are not represented on the map. No individual members of this thrust zone, therefore, have been traced continuously across the Cottonwood Divide to Alta. North and northwest of Alta there are two overthrusts that converge northwestward. The more northerly is the more clearly proved by the areal relations; where it is shown as being within the limestone it has pushed the lowest part of the formation over the highest. The more southerly overthrust is clearly exposed in the Tom Moore tunnel.

Grizzly thrust zone.

The Grizzly overthrust emerges from the southwest slope of Honeycomb Hill at about the level of the Grizzly tunnel. Although its throw is comparable to that of the Alta and Columbus overthrusts, it is rather inconspicuous, for both its walls consist of eastward-dipping metamorphosed limestone to whose bedding it is nearly parallel, and its fissure is not marked by extensive brecciation or crumpling. The presence of the fault was first suggested by the occurrence of the buff-mottled Cambrian limestone (division 7, p. 236) high on the slope and of cherty Mississippian limestone (division 6) at the foot of the hill. The magnesian Cambrian limestone just above the overthrust is crowded with crystals of forsterite; the more purely calcitic Mississippian limestone below is more coarsely crystalline, is free from forsterite, and contains lumps of chert. The fault fissure crosses the Cleves tunnel about 1,200 feet from the portal, and it is well exposed in a prospect 600 feet east of the City Rock tunnel, where it dips 45° E. and contains metamorphic minerals that show it to be older than the granodiorite.

North and west from the Grizzly tunnel the thrust plane flattens and in places even dips west. It runs under Davenport Hill and is cut off by the great Silver Fork fault. Apparently it branches under Davenport Hill, for in the basin to the northeast and on the west spur of the Prince of Wales Hill there are at least two overthrusts. The northernmost observed exposure of any fault belonging to this group is that of a thrust contact between Cambrian and Mississippian limestone in the gulch southeast of the Bodfish tunnel.

The Grizzly overthrust is cut off by the Alta-Clayton Peak stock, south of which it has not been definitely identified. Overthrusting has occurred, however, in the great area of undifferentiated limestone that contains the Devils Castle and Sunset Peak. Two or three overthrusts, broken by later faults, cross the Bullion Divide between those two summits but have not been followed out sufficiently to be shown on the map. One or more of them, presumably, form the continuation of the Grizzly overthrust.

The possible identity of the Grizzly with the Reade and Benson thrust zone is discussed in connection with the Silver Fork fault. (See p. 248.)

NORMAL FAULTS AND STEEP REVERSED FAULTS.

General features.

Among the faults whose dip is known, the so-called normal faults, with dip toward the downthrown side, are apparently not more numerous than reversed faults that dip steeply in the direction of upthrow. One fault appears to be in part normal and in part reversed; and the direction of dip of many faults whose course on the surface shows them to be steep is unknown. It is therefore impracticable to classify all these faults as being either normal or reversed.

The commonness of steep reversed faults—a condition that is not peculiar to this region—is a fact which the mining geologist may find it practically useful to bear in mind. An ore body cut off by a steep fault is generally presumed to have moved downward on the side toward which the fault plane dips, as the well-known ore body of the Emma mine actually did. It is best, however, to attack such a problem without assuming that the fault is of the type that is, perhaps unfortunately, called "normal," and to ascertain the direction of movement, if possible, by the usual methods of field geology, before undertaking exploratory development work.

In respect of strike the faults are not obviously systematic. It is found, however, on projecting their courses through a common center, that strikes approximating the cardinal directions north and east are much commoner than those very close to northeast or northwest. Sheaves of especial density extend about north-northwest and west-northwest. The widest segment that is free from known faults of appreciable throw is bisected by a line striking N. 60° E., which, however, is not far from the average strike of the mineral-bearing fissures. Faults whose strike is nearly north are especially common north of Little Cottonwood Creek, south of which east-west faults are more numerous.

No clear evidence has yet been found that there were distinct periods of faulting, each of which resulted in the formation of approximately parallel faults. Apparently, however, the east-west faults are in general the oldest. At least two of them are jogged by other steep faults, and some of them terminate against overthrust faults. Yet the Mountain Lake fault, striking east-northeast, throws the Silver Fork fault, which strikes north. The other faults, so far as observed, are all later than the overthrusts. Instances of one fault clearly thrown by another fault beyond which it can be definitely identified are not common. Some faults, on the other hand, apparently terminate against others which they meet at a large or a small angle, the relations indicating relative movement between blocks or wedges rather than between parallel slices.

Big Cottonwood fault.

The alluvial and glacial deposits in the upper part of Big Cottonwood Canyon cover a great fault which apparently causes relative downthrow to the southwest. At the mouth of Mill D South Fork the beds to the south of the main stream belong considerably above the base of the Weber quartzite, while those to the north belong, stratigraphically, at least 2,000 feet lower. Farther east the relations are more obscure; the fault probably diminishes in this direction and is cut off by the Alta-Clayton Peak stock. The fault runs up the north side of the valley beyond the point, just north of the quadrangle, at which the creek turns southwestward; its course on the slope indicates a steep dip, whose direction, however, has not been ascertained.

Silver Fork fault.

The evidence of a great dislocation which, from its alinement with the general course of Silver Fork, may appropriately be called the Silver Fork fault is clearest in the gorge of

Little Cottonwood Creek southeast of Alta. The west wall of this gorge consists mainly of limestone, and the east wall mainly of pre-Cambrian tillite; both formations dip eastward. The fault plane dips about 45° W., and the fault is most simply interpreted as a normal one, whose westward downthrow must have amounted to at least 2,000 feet. The fault is conspicuous for nearly 2 miles south of Alta and probably will be found, when the structure has been worked out in detail, to extend much farther.

This great fault must be bent or offset eastward under the drift-covered floor of Little Cottonwood Canyon and must cross the Cottonwood Divide a few yards east of the summit of Davenport Hill, for this divide is not crossed elsewhere by a fracture which resembles that in the gorge in dip, strike, and amount of displacement. The relations at this locality, so far as they are shown on the map, might be explained by an overthrusting movement of relatively slight extent from the west, resulting in the uplift and the removal by erosion of the Grizzly overthrust on this side; but this hypothesis is made untenable by facts which the map does not express. First, the youngest rock east of the fault is considerably older than the youngest rock west of it. Second, the unconformity between the Cambrian and post-Cambrian limestone immediately east of the fault and below the Grizzly overthrust is near the top of the Cambrian shale, whereas it is nearly at its highest observed level both on Honeycomb Hill and near the Montezuma tunnel.

The simplest explanation of these facts is that the block above the Grizzly overthrust is the same (aside from smaller fractures) as the block west of the Silver Fork fault, which would accordingly have caused a downthrow to the west whose least possible measure would be the difference of stratigraphic level between the rocks just east and just west of the summit of Davenport Hill. This stratigraphic throw would be, like that in the Little Cottonwood gorge, about 2,000 feet; the movement on the fault plane would be some hundreds of feet more, and the vertical displacement considerably less. To restrict the downthrow to this minimum value it is necessary to correlate the Grizzly thrust zone with the Reade and Benson thrust zone. Their difference in stratigraphic level makes their correlation difficult, though not impossible; but there is even greater difficulty in correlating the Grizzly overthrust with the Columbus or the Alta overthrust.

The Silver Fork fault zone is reached by the westerly drifts of the Silver King tunnel of the Alta Consolidated mine, where it appears as a heavy breccia in which the principal fissures have a low west dip. The fault may be thrown by certain steeper faults on the southwest slope of Davenport Hill, but its exact course is difficult to follow here in the crushed, thick-bedded limestones. The complication is even greater on the northerly slopes of the hill, which consist of one huge mass of limestone breccia produced by converging faults. The evidence of a great downthrow to the west persists to the mouth of Silver Fork, where the Silver Fork fault either is greatly offset by the Big Cottonwood fault or terminates against it.

Superior faults.

The east and west Superior faults are the two strong north-south faults that meet in Superior Gulch. At the head of Mill D South Fork they form the sides of a wedge of limestone which appears at first sight to be let down into the Cambrian quartzite. In reality, both faults effect a downthrow to the east, for the eastern mass of quartzite lies above and the western mass below the Alta overthrust. (See section A–A, Pl. XXVII.) The west fault is the greater, its estimated throw being about 1,000 feet; that of the east fault is perhaps half as great. The dip of the west fault in a prospect about northeast of the Monte Cristo mine is nearly vertical; that of the east fault, as exposed at many places in the Cardiff mine, is generally steep to the east but varies somewhat in different places.

Minor faults near Mill D South Fork.

General character.—The faults near Mill D South Fork, other than the overthrusts and the Superior faults, all depart widely from the northerly trend that generally prevails north of Little Cottonwood Creek; they strike about east, northeast, and southeast. Many of them are poorly exposed, the structure in the canyon bottom north of the Cardiff mine being especially obscure. The more interesting of the faults are those that may be called the Carbonate, the Evarena, the Sampson, and the Ophir.

Carbonate fault.—The Carbonate fault strikes south-southeastward from the Carbonate mine and is conspicuous on the steep west slope of the South Fork canyon. This fault has perhaps a greater throw than any other in the quadrangle except the principal overthrusts and other major faults already described; the displacement by which it brings limestone against Cambrian quartzite is necessarily more than 500 feet. It terminates, however, against the West Superior fault, beyond which it has not been found. It cuts an overthrust supposed to be the Alta. Its dip is about vertical in the Carbonate mine, where it cuts off the ore.

Evarena fault.—The Evarena fault, which extends northeastward from the East Superior fault near the Cardiff mine, is named for a mining claim that parallels it on the northwest side. Its downthrow to the northwest of about 300 feet is proved by the offsetting of Cambrian strata and of the Reade and Benson thrust zone, as inferred from scattered outcrops on a gentle slope that is partly mantled with talus. The fault has formed a strong breccia in the Mississippian limestone to the east, and the main fissure in this breccia dips 75° NW., indicating that the fault is a normal one.

Sampson and other east-west faults.—The Sampson fault, which passes a few rods south of the Sampson shaft, is chiefly remarkable for its ambiguous relation to two overthrusts; it offsets the upper of these and is cut off by the lower. Apparently it was formed within the period of overthrusting.

Another east-west fault of similar relations is postulated to explain the apparent abutting of older against younger limestones east of Montreal Spring, but this fault is hardly proved. On the other hand, a well-exposed but partly inaccessible vertical east fault south of the Sampson fault is thought to be younger than the overthrusting.

Ophir fault.—The fault that strikes southeastward from the Cardiff mine may be called the Ophir, from one of the claims that it crosses. It is much obscured by talus, but its presence is proved by fairly numerous outcrops which indicate a downthrow of at least 200 feet to the northeast. At the Cottonwood Divide there are complications which are not fully understood, and the fault has not been traced any farther southeast.

Minor faults crossing the Cottonwood Divide.

General character.—The Cottonwood Divide is crossed by numerous faults of nearly north strike, many of which are readily traceable on the steep high slopes, where some are marked by prominent limestone breccias; but on the lower part of the slope toward Alta they become so much obscured by waste and glacial drift that their relations, which have considerable economic significance, remain in large part to be worked out by further underground study.

One of the fractures, locally called the Snow fault, has a low northwesterly dip and a downthrow to the northwest. The other faults are all fairly steep, and the downthrow of most of them is on the east side; several of them are known to be reversed faults, and none are known to have a "normal" dip throughout. The faults that seem to deserve separate notice, named in order from east to west, are the Snow, Montezuma, Vallejo, and Flagstaff.

Snow fault.—The Snow fault may best be observed on the Tom Moore tunnel level of the Wasatch Mines Co., where it forms a zone of strong fissuring and crushing in which the fissures dip 25°–55° WNW. It is not well exposed on the surface, and its relation to some of the north-northwest faults which the map shows as being cut off by it is in fact uncertain. There is better evidence that the Snow fault is offset southeastward by the Montezuma fault and is represented by a zone of strong brecciation that may be followed continuously across the Cottonwood Divide, just south of which the breccia forms two or three bold crags. If this interpretation is correct, the course of the Snow fault on the surface indicates a steepening of dip or a change of strike or both about 1,200 feet east of the Montezuma tunnel. North of the crest the Snow fault apparently converges with the Silver Fork fault, which it resembles in its low west dip, strong brecciation, and normal character and of which it may be a branch.

Montezuma fault.—The slumping of the surface rock toward the old caved stopes of the Emma mine has left exposed, beside the portal of the Montezuma tunnel, an overhanging fissure wall that strikes N. 42° W. and dips 70° NE.

Halfway up the slope between this place and the Cottonwood Divide the Tiger cabin leans against the boldly cropping breccia of a fault that strikes N. 15° W. and dips 80° W. It is believed that both exposures represent a continuous fracture, which may be called the Montezuma fault.

There are, however, certain difficulties in supposing the fault continuous. First, it is normal at the Montezuma tunnel and reversed at the Tiger tunnel, the downthrow at both places being to the east; second, its change of strike appears to take place at an angle rather than a curve. Continuity, on the other hand, is argued by two other facts; the dip of the fissure in a prospect near the bend is 85° E., or intermediate between the opposing dips already mentioned, and the downthrow north of the bend, as measured by the crinoidal bed of the Mississippian (division 7, p. 238), is approximately equal to that southeast of the bend, which, as measured by the Emma ore body, amounts to about 300 feet. The caved stopes already mentioned were in the segment of this ore body lying southwest of the fault; the downthrown eastern segment was recovered in 1917, after some 40 years of desultory search, through exploration based on the geologic study of J. J. Beeson.

Vallejo fault.—The Vallejo fault, which is the first one east of the Eclipse shaft, derives its name from the fact that the portal of the Vallejo tunnel lies on its course. This fault causes a downthrow of about 150 feet to the east, best measured by the displacement of the white crinoidal limestone on cliffs north of the Cottonwood Divide. Its dip as noted at two or three places on the upper part of the slope is about 70° W., or in the direction of upthrow; the Vallejo fault thus appears to be of the steep reversed type, but its dip at the Alta level is not known.

Flagstaff fault.—The Flagstaff fault is the first one west of the Flagstaff tunnel. It is a steep reversed fault, its dip being about 65° W. and its downthrow to the east. The amount of downthrow is about 150 feet. The Flagstaff fault is met near the Cottonwood Divide by a vertical fault of north strike. It is marked near the Flagstaff tunnel by a strong breccia, but it becomes obscure on the lower part of the slope toward Little Cottonwood Creek, and it may be cut off by the Snow fault.

Minor faults near City Rock Gulch.—The Cambrian shale and quartzite along the bottom of City Rock Gulch are broken by several small faults that are not shown on the geologic map (Pl. XXVII), and at the west they are brought into contact with limestone by a fault that dips about 50° NW. and may be a part of the Silver Fork fault. The whitish limestones along the lower part of the gulch are clearly affected by numerous faults but are so much altered that their stratigraphic position can hardly be determined; and the throws of the faults therefore can not be measured. The gentle slopes north and south of the rocky stream channel are strewn with morainic material, which greatly obscures the structure and adds to the difficulty of mapping.

Just south of City Rock Gulch the Cambrian shale is limited on the east by a dike which apparently occupies the fissure of a fault with downthrow on the east, for the east wall of the fissure consists of cherty Carboniferous limestone.

Minor faults near Honeycomb Fork.—The thick series of limestone beds exposed in the Honeycomb Cliffs are deformed and folded and are cut by strong northeasterly fissures, most of which contain dikes. At many of these fissures there is so abrupt a discordance in the attitude of the strata on either side as to suggest faulting, but at only one fissure, which contains no dike, has a fault of appreciable throw been proved. This Honeycomb fault, to use the obvious name, is reversed and dips for the most part rather steeply to the northwest, but at the base of the cliff it is sharply contorted as a result of later movement.

Another fault, which strikes east and has caused apparent downthrow to the north, forms the north boundary of the Cambrian limestone in the bottom of the canyon. This fault may be called the Woodlawn, from the mine of that name which lies just south of it. The effect of the Woodlawn fault becomes rather obscure in both directions from Honeycomb Fork. It is thought to be, like the Sampson fault, older than or contemporaneous with the overthrusts of easterly dip.

Minor faults south of Little Cottonwood Creek.

The faults south of Little Cottonwood Creek have been studied less thoroughly than those farther north, and the direction of dip of none

of them is known. Most of them fall naturally into four local groups.

Devils Castle group.—The faults on the east side of the main headwater basin of Little Cottonwood Creek possess in common an easterly strike, though they converge a little toward the west. Some cause a downthrow to the south, others a downthrow to the north. The southernmost and greatest, which may appropriately be called the Pittsburgh fault. The downthrow on this fracture can not be less than 500 feet to the north.

Faults northwest of Mountain Lake.—The Mountain Lake fault, which is nearly tangent to the north side of Mountain Lake, has, as mapped, an ambiguous effect on the distribution of the rocks; it offsets the great Silver Fork fault westward, which indicates a downthrow to the south, but the relations farther east suggest a downthrow to the north.

This fault forms one of a group of fractures which radiate from Mount Baldy (though having no significant relation to it) and which include some dike-filled fissures north of the Mountain Lake fault.

Faults at head of American Fork.—The mosaic of faulted blocks at the head of American Fork may be, in a sense, the southward continuation of the Silver Fork fault, for the general result of the faulting at this place is a downthrow to the west. No special effort has yet been made to trace the Silver Fork fault southward.

Faults near Peruvian Gulch.—Four east-west faults lie athwart Peruvian Gulch, forming a system that may perhaps be regarded as a westward continuation of the Devils Castle group, but the downthrow is on the north side in every case. A fault near the head of Collins Gulch has the same character, but another fault that crosses Collins Gulch lower down resembles the nearest of the Devils Castle group in having an easterly strike and causing downthrow to the south.

MINERALIZED FISSURES.

The movement that has occurred along the mineralized fissures has apparently been slight, and they are not marked by strong breccias such as those that follow some of the faults. They are comparatively inconspicuous at the surface, being recognized only as seams or narrow breccias, which are stained brown with oxides of iron and manganese. The brecciation is most marked in certain beds of limestone.

The fissures range in strike from north through northeast to east. Most of those noted near Mill D South Fork strike about N. 35°–40° E. and dip 60°–65° NW.; the Carbonate fissure, however, strikes about N. 75° E. and dips 70° N. The principal fissures near Alta strike N. 60°–70° E. and dip 60°–65° N. Those in the American Fork district appear to belong to two systems, one of northeasterly and one of easterly strike. The stopes of the famous Miller mine extend in both directions, the longest N. 85° E. The Pacific vein and the Dutchman vein belong to the northeasterly system. Far to the northeast again two systems are found. In the Barry-Coxe mine, on the north slope of the pass between Silver Lake and Park City, the mineralized fissures strike about north and east; the northerly fissures are the more heavily mineralized.

SOME GENETIC RELATIONS OF THE STRUCTURAL FEATURES.

Wasatch and Uinta elements.—Perhaps the most broadly interesting problem upon which light is thrown by the geologic structure of the Cottonwood-Park City region is that of the relative age of the Uinta Range and of the primitive Wasatch uplift, without regard to the late rejuvenescence of the Wasatch Range by faulting. Both ranges were formed primarily by uplift and deformation, and the structural features of this region, which lies at the intersection of their axes, are related in part to the Uinta uplift and in part to the Wasatch uplift. It is possible to separate, at least in part, the Wasatch elements from the Uinta elements and to determine the relative age of the groups thus formed.

The Wasatch Range as a whole is characterized by north-south folds, and the more fully its structure is understood the more these folds are found to be accompanied by overthrusts of nearly north-south strike. Both the overthrusting and the longitudinal folding are plainly the result of tangential pressure acting from the east and west, and the two kinds of deformation were probably almost contemporaneous.

The Uinta Range, on the other hand, was formed by a relatively simple uplift along an easterly axis. The line of this axis, west of the Uinta, is marked by a row of intrusive

bodies. This fact can hardly be accidental; whether the intrusion caused the uplift or the uplift caused the intrusion, the two activities must have been causally connected and virtually contemporaneous.

In the complex structure of the Cottonwood-Park City region, the Uinta elements are chiefly represented by the intrusive rocks and by the Park City anticline. The eastward plunge of the anticline, however, is regarded as a Wasatch element. It may conceivably be due to one or more of the following causes: (1) Tilting of the Wasatch Range as a whole at the time of the faulting along the west face; (2) a bodily eastward tilting of the anticline by later Wasatch folding; (3) differential upward pressure by intrusive bodies; (4) an eastward inclination of the beds before the Uinta uplift.

The first-named cause can not have been important, for the physiographic evidence indicates that the tilting correlative to the faulting was very much less than that evinced by the general eastward dip of about 30° along the axis of the Park City anticline. This tilting merely increased an inclination that was already pronounced.

The assignment of the Wasatch deformation to a later date than the Uinta uplift is negatived by the relation of the overthrusting (a Wasatch feature) to the intrusion (a Uinta feature). The overthrusting is earlier than the intrusion: the Columbus overthrust is crossed by at least one dike of soda granite porphyry; the fissure of the Grizzly overthrust carries metamorphic minerals that must have been formed by the passage of emanations from the magma; and neither this overthrust nor any other, so far as known, has fractured the Alta-Clayton Peak stock. The second of the possibilities proposed above is thus eliminated; the Wasatch deformation is the earlier, on the assumption that the obvious grouping of the major structural features is accordant with the facts of genesis.

Evidence, independent of this last assumption, that not only the intrusion but the Uinta folding was later than the overthrusting would be supplied if the overthrusts were shown to have the same northeastward convexity as the sedimentary strata. Unfortunately, no endeavor has been made to trace the overthrusts to an end, and their curvature for the short distances that they have been traced is hardly decisive; but if the thrust contact south of the Carbonate mine is, as is believed, a part of the Alta overthrust, its westerly strike, in general accordance with that of the adjacent strata, confirms the hypothesis.

It may be asserted with much confidence, therefore, that the earliest deformation of the strata exposed in the Cottonwood-Park City region was effected by folding and overthrusting on north-south lines. These strata form a part of the western limb of the Great Logan syncline which has been deformed by the agencies that gave birth to the Uinta Range.

Relation of intrusion to deformation.—The eastward pitch of the Park City anticline is thus explained without invoking differential uplift by the exposed intrusive bodies. Whether uplift all along the Uinta axis was caused primarily by injection of igneous material that remains wholly concealed in the Uinta Range itself is another question, upon which the writer feels unprepared to pronounce a final opinion. There are some structural features that suggest, at least, that the intruded magma deformed or dislocated the sedimentary rocks.

The most obvious suggestion of the bending of strata by intrusion is given by the general dip of the strata away from the Little Cottonwood stock; but the walls of this body cut across the strata in great part, and its western wall, if it were visible, might prove as radically discordant with the bedding as the western wall of the Alta-Clayton Peak stock is readily seen to be. The dip of the strata around the Alta-Clayton Peak stock is not quaquaversal; the fact that they dip outward from it farther east results necessarily from the position of the stock on the axis of an anticline; and the same is true of the Little Cottonwood stock. Although the evidence of doming is thus ambiguous, a suggestion of nearly horizontal pressure acting outward from a steep wall is conveyed by the minor folds in Honeycomb Hill and by those near Superior Gulch. (See p. 244.) Some instances of minor folding caused by intrusion in the Park City district are cited by Boutwell.[1]

The mineralized fissures and most of the faults other than overthrusts are later than the Wasatch folding and overthrust faulting. It

[1] Boutwell, J. M., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, p. 97, 1912.

is natural to seek for evidence of genetic relationship between these later fractures and intrusion, for intrusion, whatever its mechanism, must be attended by some fissuring of the surrounding rocks, and the readjustments attendant on contraction of the cooling magma must cause some dislocations. Unfortunately the relations between faults, fissures, and intrusive bodies are much obscured at critical localities by surficial deposits; some more or less tentative conclusions, however, may be deduced from the facts that are known.

There are several indications, quite independent of most of the arguments advanced by Mr. Butler (see p. 283) in support of a genetic relation between the ore deposits and intrusion, that the formation of the mineralized fissures was due to the intrusion of the stocks.[1] The strike of the great majority of these fissures is about east-northeast, or parallel to the alinement of the intrusive stocks. Not only is it to be expected that intrusion would give rise to fissures of this trend, but this is actually the trend of most of the dikes, which must have been injected into fissures opened by the intrusion. Where, as at some places in the Big Cottonwood and American Forks districts, the mineralized fissures depart from the usual east-northeast direction, they are either parallel or radial to the periphery of the nearest intrusive body, and in either case may well be related to it. In the Dutchman, Live Yankee, and Miller mines of the American Fork area the veins are bordered by dikes on one side for parts of their courses, though the dikes are somewhat earlier than the veins. The ore-bearing fissures, then, were pretty clearly formed as a result of the intrusion but were not mineralized at the very beginning of the igneous period.

Some of the faults are known to cut igneous rocks and ore bodies. The best known instance of postmineral faulting is the displacement of the Emma ore body by the Montezuma fault. The Live Yankee vein is broken by a fault that makes a rather small angle with the mineral-bearing fissure. The east Superior fault cuts off the Cardiff ore body. All these postmineral faults are presumably later than the period of intrusion, and many other faults can be directly observed to cut intrusive rocks. The outcrops of soda granite porphyry found near a line which extends from the Wasatch drain tunnel to Honeycomb Fork probably belong to a single large dike, but if so this dike is thrown by several faults, though it crosses the Grizzly overthrust with only a slight jog which is probably due to a swerving of the dike-filled fissure at its intersection with the thrust plane. The great Silver Fork fault has affected the intrusive rocks; it jogs the boundary of the Alta-Clayton Peak stock in the gorge of Little Cottonwood Creek, and farther south it cuts off numerous dikes of granodiorite porphyry. It also cuts off the ore-bearing fissures whose course it intersects. Some east-west faults appear to be cut off by the Little Cottonwood granodiorite. The relation of many faults to intrusive bodies and to the ores is indeterminate.

Despite the doubt concerning the age of some of the faults, it is clear that faulting began before intrusion and ended after the intrusive rocks now visible had solidified. It can hardly be doubted that some of the faulting is due to unequal subsidence of the crust above a cooling mass of magma, which at a certain depth presumably underlay a large continuous tract that included all the area in which intrusive rocks are now exposed; and some faulting may have been caused by differential upward movement of the magma. The latter agency affords a possible explanation of the abundance of steep reversed faults, which are not easily accounted for by the simple lateral stretching of the crust that is generally supposed to be the cause of normal faulting. Steep reversed faults appear to presuppose the action of forces whose chief component is vertical. The movement on the Montezuma fissure, if this fissure is, as supposed, concave eastward in vertical section, involves a differential tilting of the blocks on either side, the west edge of the block to the east having swung downward. Such movement in the roof of an unsolidified magma is not difficult to imagine.

Even faults that dislocate the visible igneous rocks may be due to movements in deep-lying parts of the magma chamber, where solidification occurred later than at the levels accessible to observation. An instance of a fissure in granite that dies out in depth is

[1] The facts relating to the mineralized fissures are taken from Butler, B. S., and Loughlin, G. F., A reconnaissance of the Cottonwood-American Fork mining region, Utah: U. S. Geol. Survey Bull. 620, pp. 180-181, 1915.

described by Mr. Butler on page 199, and some of the post-mineral faults of the Cottonwood district might similarly vanish at the depth of a few thousand feet. The extent to which this relationship exists is, however, a highly speculative question. It is probable that some of the faults are unrelated to intrusion; some of the later ones may have been formed at the same time as the great fault that defines the Wasatch front, and this fault is so recent and so extensive that it can hardly be related to the intrusions of the Bingham-Park City zone. The Silver Fork and Snow faults resemble the Wasatch fault in their low westerly dip, but since they have no direct expression in the topography and are thrown by other faults they may well be of earlier date.

SUMMARY.

The earliest deformation of the strata in this region was the Wasatch folding and overthrust faulting along north-south lines. The strata, having been thus tilted eastward and reduplicated by thrust faults of eastward dip, were bent upward and invaded by granodiorite magma along the east-west Uinta axis, simultaneously with the formation of the Uinta Range. The mineral-bearing fissures probably were formed at an early stage and mineralized at a later stage of the period within which the magmas were intruded and became solidified. Normal faults and reverse faults of steep dip began to be formed in the period of overthrusting. Probably a large proportion of the faults were formed in the period of intrusion and solidification, and many of these may have been due to movements of the magma. Some are more recent than the igneous rocks and the ores; these may be due in part to adjustments in the deep-seated, late-solidifying portions of the magmas, but they may be due in part or wholly to other causes.

HISTORY.

By V. C. Heikes.

LITTLE COTTONWOOD DISTRICT

DEVELOPMENT.

Ore was first discovered in the Little Cottonwood district by Gen. Conner's soldiers in 1864, and the Wasatch district was then organized, but it was soon abandoned owing to the great expense of working.

In 1867 most of the claims were "jumped" and the Mountain Lake district, which included a large area in the Wasatch Range, was organized. It was divided in 1869–70 into the Little and Big Cottonwood, American Fork, and Uinta districts. The mining claims recorded in the Little Cottonwood district covered an area about 2½ miles square. Alta, the principal camp, is 16 miles east of Sandy, a station on the Denver & Rio Grande and Los Angeles & Salt Lake railroads. A railroad was completed to the district in May, 1873, but was discontinued a few years later. In 1913 the grade was repaired and rails laid as far as Wasatch for the transportation of building stone to Salt Lake City. The mine operators in the district took advantage of this renewed method of transportation, thus saving a wagon haul of 9 miles to the smelters. In 1916 construction on a narrow-gage extension of the road to Alta was begun, and in 1917 it had been extended to a point a short distance below Alta.

The most productive period was between 1871 and 1877. At the time of Huntley's visit[1] (October, 1880) only two mines—the Vallejo and the City Rock—were working regularly, the others having closed down, for several causes, including legal troubles, the exhaustion of working capital, the giving out of surface bodies, the finding of pyrite and water in the lower levels, and the low price of lead.

Very little metallurgic work was ever done in the district, as most of the ore was sold in the Salt Lake market. In 1866 the owner of the North Star mine built a Scotch hearth furnace and ran out about 3 tons of lead. In the following year he erected a reverberatory furnace, which succeeded, and a cupel furnace, which failed. The Jones smelter, about 4½ miles from the mouth of Little Cottonwood Canyon, was operated in 1871 and ran on custom ores for two years. In 1872 or 1873 the Davenport smelter was started at the same place. In addition to the ore from the mine it worked some custom ore but was shut down in 1875. The Flagstaff Co. also erected three stacks in this vicinity. Several unsuccessful attempts were made to leach ores on a small scale. Concentration works were built for the Emma

[1] Huntley, D. B., The mining industries of Utah: Tenth Census U. S., vol. 13, p. 422, 1885.

mine and were financially successful, though the percentage obtained was low.

MINES.

The history of the Emma and other mines was given by Huntley[1] in 1880, as follows:

The Emma mine * * * was located in 1868 by Woodman, Chisholm, Woodhull & Reich. Little work was done until the autumn of 1869, when the ore body was struck. Some ore was shipped and sold prior to the sale of the mine to the Emma Mining Co., of New York, in 1870. This company worked the mine quite vigorously and shipped a large amount of ore. The following year the property was sold to the Emma Silver Mining Co. of Utah (Ltd.) for $5,000,000 cash; another authority placed the price at $3,500,000. The mine was then worked by English managers, paid $300,000 in dividends (one authority says $1,300,000) until September, 1874, when it was attached by T. W. Park and others for an indebtedness of $300,000. It was then idle until October, 1877, when the American Emma Mining Co. was incorporated and work resumed. The second ore body failed in the autumn of 1873, up to which time most of the ore had been shipped to Swansea, Wales. During the years 1873, 1874, 1878, and 1879 much low-grade ore was concentrated by jigs.

When the American Emma Mining Co. began work it first prospected the old ore bodies and then leased the Bay City tunnel, which was 1,700 feet long and 90 feet below the lowest old workings of the Emma. This tunnel had been run by a St. Louis company at a cost of $75,000 and had been abandoned in 1876. Since making the connection a small ocher-stained seam, in an incline or winze 130 feet below the tunnel level, has been followed. * * * From Mr. Charles Smith, of Salt Lake City, whose accounts included all but the first few hundred tons sold, the writer learned that the sales of ore to June 1, 1880, amounted to 27,451 tons, for which $2,637,727.44 was received. (See also p. 261.)

The Flagstaff mine * * * was located in 1869 by Groesbeck, Schneider, and others, who worked it under the name of the Salt Lake Mining Co. until February, 1872, when it was bonded to one Davis for $300,000, who sold it to English capitalists for $1,500,000. They organized the Flagstaff Silver Mining Co. of Utah (Ltd.) and worked the mine in a very expensive manner until December, 1873, when the ore bodies in sight gave out. * * * Davis took the mine and worked it under agreement with the company until December 24, 1876, when he was dispossessed by the United States marshal under orders from the English directors. Heavy lawsuits with small results followed. Since 1876 the mine has been leased and subleased many times, but has been idle since the summer of 1880. At the time of examination it was owned by Seligman Bros., of New York, who took it for debt. * * * The English company erected the Flagstaff smelter (three stacks) at the mouth of Little Cottonwood Canyon and ran it until November, 1873, when they leased the Last Chance smelter near Sandy. Smelting was not as profitable as selling the ore, which after April, 1876, was disposed of in the Salt Lake market. The dividends paid to the English company amounted to about $350,000. The property consists of the Flagstaff, South Star and Titus, Virginia, and Nabob. The Flagstaff is 2,200 by 100 feet, but it extends across and not along the belt.

The total product was estimated by the superintendent to be 100,000 tons. Of this, 30,000 tons probably assayed $10 gold, 60 ounces silver, and 40 per cent lead and sold for or was worth $80 per ton. The remainder probably assayed $4 gold, 30 ounces silver, and 20 per cent lead and was worth $30 per ton. * * *

The South Star and Titus, an older location than the Flagstaff, has been constantly harassed by lawsuits. Several hundred thousand dollars' worth of ore has been extracted. * * * Active work ceased in 1878.

The Nabob was located in 1876. A large body of ore, lying partly in the Virginia ground, was struck in the winter of 1876–77, which yielded about $100,000. * * * An ore body, 30 by 25 by 4 feet, was found not 50 feet from the surface. The average assay of this ore was $74.76, of which $26 was gold. * * *

The Joab Lawrence Co., the principal actively working company on Emma Hill at the time of the writer's visit, was organized in the spring of 1879. Its property consists of the Vallejo and the North Star, adjacent claims, situated between the Emma and the Flagstaff. The North Star was one of the earliest claims of the district, having been located in 1865, and has yielded largely. * * * The Vallejo was worked in 1872, 1873, 1874, 1875, and 1877 by several companies, and much ore was extracted. * * * It [the ore] was fine and contained from 20 to 45 per cent lead and from 15 to 90 ounces silver, from 20 to 35 per cent iron and from 9 to 14 per cent of moisture. It was in great demand among the smelters owing to the lack of silica and the presence of so much iron. A low grade of ore containing from 40 to 50 per cent of iron, no lead, and a few ounces of silver was also shipped. * * *

The Toledo-Utah Silver Mining & Smelting Co. bought the Toledo mine shortly after its discovery in 1872 and worked it quite extensively until April, 1880. The property consists of the Toledo and the Fuller claims. On the latter most of the ore has been found and most of the work done. * * *

The Emily mine is situated in a small ravine between the Toledo and Emma Hill. It was discovered in 1870. It is owned by the Emily Mining Co., of Pittsburgh, Pa. They ceased regular work in 1874, and the mine has been leased since at one-fifth royalty. It is a bedded vein of clay slate in quartzite, dipping about 60° E. The ore is from 1 to 6 inches wide and consists of quartz containing pyrite, sphalerite, galena, and tetrahedrite. When sorted it assays from $80 to $100. * * *

The City Rock and Utah group is situated at the head of Little Cottonwood Canyon and comprises the Utah, 100 by 1,000 feet; City Rock, 100 by 1,000 feet; West Wind, 100 by 495 feet; King of the West, Utah No. 2, Utah No. 3, and Freeland. The first three are on the Utah vein, and the others are on the parallel King of the West vein, 200 feet distant, and have but little development. * * *

[1] Tenth Census U. S., 1880, vol. 13, p. 423, 1885.

The other mines of the Little Cottonwood district are:

Mine.	Total length of openings.	Total products.	Remarks.
	Feet.		
Cincinnati group	1,500	$10,000	Ore, a sulphuret containing considerable zinc.
Enterprise	500	....	One ore body yielded $10,000 or more.
Dexter Consolidated	300	Small.	
Brian lode	....	([a])	
Marion group	1,800	....	
Manitoba	630	....	Vein not well defined.
Emily	800	18,000	Ore assays $80 to $100 per ton.
Caledonia	700	....	Several thousand dollars have been extracted.
Highland Chief	1,100	....	Ore assays 20 ounces silver and 25 per cent lead. Many hundred tons have been shipped.
Ohio River group	500	60,000	
Savage and Montezuma group	3,000	200,000	Ore 35 per cent lead and 35 to 150 ounces silver.
Stoker	450	Small.	Ore medium grade.
McKay and Revolution	1,000	....	A few hundred tons have been extracted.
Grizzly and Lavinia	3,000	Large.	Contains large bodies of low-grade ore.
Darlington	500	Small.	
Davenport	4,800	600,000	
Island	1,000	....	Do.
Siskiyou	500	Small.	
Alpha	500	37,000	Average assays: 200 ounces silver, 10 per cent lead, $10 gold.
Evergreen	....	....	
North Pole	300	....	Ore, galena in small seams in limestone.
Albion and Rising Sun	1,800	100,000	
Oxford and Geneva	1,910	20,000	Ore assays 30 to 90 ounces silver, 40 to 60 per cent lead, $3 gold.
Louisa	600	8,000	Ore, 10 to 12 ounces ochery carbonate and 40 to 50 ounces galena.
Sedan	300	Small.	Ore, cerusite, galena, and pyrites, containing 16 to 60 ounces silver.
Fritz	460	Small.	Vein, 20 feet; soft, low-grade ocher.
Peruvian	700	Small.	A few tons shipped, assaying 40 to 60 ounces silver, 40 to 70 per cent lead, and $6 gold.
Kenosha	500	Small.	
Highland Boy	500	None.	Small stringers of carbonate ore in limestone.

[a] A few thousand dollars.

TUNNEL SITES.

The topography of this district is very favorable for the location of tunnel sites. Accordingly, in early times work was begun upon a great many. They have cost fortunes but have rarely been successful in finding ore; and though all are still claimed, few are worked more than is sufficient for assessment work. These tunnel sites, in a legal way, are a great drawback to the district. They were located before many of the present claims; they ran in all directions, and, in case large and rich ore bodies should be found, some of them might be used to make serious legal difficulties. The following are the principal tunnel sites in the order of their situation, beginning at the west, on the north side of Little Cottonwood, and continuing in a semicircle around the head of the canyon:

Frederick tunnel.—This was driven to develop the Fredcrick and Crown Point claims. These are parallel veins, 70 feet apart, 3 and 4½ feet wide, dipping 54° N. in limestone and between limestone and quartzite. The ore is a carbonate, 18 inches wide, and averages 60 ounces silver and 35 per cent lead. The claims were located in 1870 and were worked until 1873, when water and galena were encountered at a depth of 337 feet. The value of the ore sold was estimated at $35,000. The mines were leased until May, 1876, when the tunnel was begun. * * *

Howland tunnel.—Work was begun on this several years ago. It has been relocated several times and was, at the period under review, known as the Solitary. Its length is 600 feet. * * *

Geneva tunnel.—Abandoned. Length unknown.

Lady Emma tunnel.—Length, 370 feet. Relocated and called the Prince of the Hills. * * *

Chicago tunnel.—Length, 600 feet. Relocated and called the Fitzgerald tunnel.

Vallejo tunnel.—Used in the early development of the Vallejo mine.

Utah tunnel.—Relocated as the Burgess and used to work the Vallejo mine.

Gladiator tunnel.—Length, about 1,000 feet. Used to work the North Star mine.

Great Salt Lake Tunnel & Mining Co.—This is better known as the Buffalo tunnel. It was located in 1871, is 600 feet in length, and is regularly worked, 275 feet having been run the preceding year. This company has located two claims, the Buffalo and another, having 9-inch veins, containing galena and pyrites. Three small bodies were found. The ore sold for about $80 per ton and yielded a few thousand dollars. The Allegan mine, operated through this tunnel, has about 550 feet of cuttings and yielded a few thousand dollars some years ago.

Bay City tunnel.—Length, 1,700 feet. * * *

Illinois tunnel.—Length, 800 feet. * * *

Equitable Tunnel & Mining Co.—This company's tunnel is about 1,500 feet in length, with side drifts and winzes amounting to 900 feet, and is situated above the Bay City. * * *

Little Cottonwood tunnel.—Relocated and called the Buckland. It is 600 feet long and was run to tap the Savage and Montezuma group.

Reliance tunnel.—Abandoned. Little work done.

Manhatten tunnel.—Abandoned and relocated as the McKay and Revolution. Length, 500 feet.

Ely tunnel.—Abandoned.

Phoenix tunnel.—Owned by the Equitable Tunnel & Mining Co. Length, 700 feet.

Herman tunnel, known as the Tilden.—Length, 500 feet.

Emma Hill tunnel.—Length, 900 feet.

Victoria tunnel.—Length, 900 feet. Used to work the Victoria, Imperial, Emma May, and Alice mines. These have a large amount of cuttings, have shipped considerable ore, and are being worked upon lease.

Christiana tunnel, known as the Oneida.—Length, 250 feet.

Brewer & Lapham tunnel.—Length, 150 feet. Located to develop the Darlington mine.

Lady Esten tunnel.—Length, 300 feet. Owned by the Equitable Tunnel & Mining Co.

Iris Tunnel Co.—This was a San Francisco company which began work in the spring of 1872 and failed in the autumn of 1877, having spent about $100,000. The tunnel was taken by one of the creditors for debt. The property consists of eight locations and two sites on Emerald Hill. * * *.

The Etna, St. Joseph, Wasatch, Silver Belt, and Rothschild tunnel sites are of varying lengths and have all been abandoned.

Besides the tunnels above mentioned, there are many others having more or less development.

BIG COTTONWOOD DISTRICT.

The Big Cottonwood district, organized July 11, 1870, is in Big Cottonwood Canyon, in Salt Lake County, north and east of the Little Cottonwood district, and is bounded by the summits of the ranges on each side of the canyon. Most of the mines are on the southern ridge. Since the earliest days most of the ore has been hauled by wagon down the canyon to Sandy, at present a station of the Denver & Rio Grande and Los Angeles & Salt Lake railroads, or directly to the smelters and samplers in that vicinity.

The Maxfield mine is on the north side of Big Cottonwood Canyon, 14 miles east of Sandy and a quarter of a mile from Argenta, which in the seventies was the principal mining camp of the district. During 1880, according to Huntley,[1] it produced about 90 tons of lead ore, containing 30 to 100 ounces of silver, which was sold for $4,518. The value of the product prior to 1880 was roughly estimated at $20,000. No records of the total quantity of silver and lead produced from the mine are available, but $1,053,000 would cover [2] the total yield to the end of 1906. Since 1906 lessees have produced some lead ore each year. The total dividends paid by the Maxfield Co. amounted to $118,000. The mine was pumped out early in 1915. In 1916 ore was produced from the lower levels and prospecting was being done on the tunnel level.

On the south side of Cottonwood Canyon, between Honeycomb and Silver Forks, 2½ miles northeast of Alta, is the Prince of Wales group, consisting of the Antelope, Prince of Wales, Wandering Boy, Highland Chief, Wellington, and Warrior claims. All were discovered about 1870. The Prince of Wales group is credited with a production of 10,121 tons of ore[3] to the end of 1890. Since that time a very little has been produced by lessees, who in 1909–1911 shipped ore containing 0.01 ounce of gold and 90 to 144 ounces of silver to the ton, 1.25 to 3.75 per cent of copper, and 12 to 21 per cent of lead. In 1915 lessees opened the ore body on the lower tunnel level, and in 1916 and 1917 ore was extracted above this level. Assays made on shipments in 1879 show the lead to have averaged between 25 and 48 per cent and the silver between 61 and 224 ounces to the ton.

The total value of the ore produced from the Prince of Wales group between 1870 and 1890, including a few shipments since, is variously estimated from $1,012,000 to $2,000,000.

The Richmond and Theresa claims, south of the Prince of Wales, produced lead-silver ore valued at $150,000 to the end of 1880. The Reade and Benson claims are often mentioned in early reviews as producers of rich ore. Subsequently these and other claims in the vicinity were incorporated into the Kennebec group, whose record as a producer was not important. The total product to 1880 is placed at $600,000.

The Ophir, discovered in 1870, produced about $30,000 worth of ore to 1880.

The mines of the Kessler Mining Co., later purchased by the Carbonate Co., are estimated

[1] Huntley, D. B., op. cit., p. 428.

[2] Personal statement of A. L. Thomas, jr., Salt Lake City.

[3] Compiled from reports of Director of Mint and commissioners, 1870–1890.

to have produced ore valued at about $380,000 previous to 1880.

Other mines active in the district previous to 1880 are mentioned by Huntley as follows:

Mine.	Total length of openings.	Total product.	Remarks.
	Feet.		
Silver Mountain Mining Co.	500	$10,000	Ore assays 50 ounces silver, 35 per cent lead, and $3 gold.
Thor and Bright Point	500	2,000	Ore assays 60 to 100 ounces silver and 40 to 60 per cent lead.
Elgin Mining Co.	700	Small.	Veins small.
Puterbaugh	300	[a]840	
Imperial Mining, Milling & Smelting Co.		Small.	A few hundred feet of cuttings. Worked irregularly for two other years.
Dolly Varden	1,400	25,000	Property in litigation.

[a] During 1880.

AMERICAN FORK DISTRICT.

The American Fork district, at the head of American Fork canyon, was organized July 21, 1870, and has an area of 6 square miles. The mining town, called Forest City, was 18 miles from the town of American Fork. In later years, since the decline of the Miller mine, the district has yielded only a small production.

The following notes are abstracted from Huntley's[1] review of the conditions in 1880:

The Miller mine, formerly the principal mine of the district, was discovered in September, 1870, and was sold the following year for $120,000 or over. The Sultana smelter (three stacks) was erected in 1871–72 and ran irregularly until the spring of 1875. In 1871–72 a narrow-gage railroad was built up the canyon to within 4 miles of the smelter, and 25 stone charcoal kilns were constructed. The ore bodies gave out, and the company shut down the mine in 1876, since which time it has been worked only on lease. The charcoal kilns, which were of the beehive pattern and held about 25 cords each, ran almost continuously from 1872 to 1877, making coal for the Salt Lake smelters. The track was taken up in 1878 and the iron sold. The bottoms of the old furnaces were torn up to get the large amount of lead contained in them, and the old slag dumps were profitably picked over four times to find scraps of lead, unreduced ore, and matte. Estimates of the total product and the average grade of the ore of the Miller mine range from 13,000 to 15,000 tons, assaying from 40 to 54 per cent lead, from 30 to 47 ounces of silver, and from $2 to $10 gold. (See also pp. 263–265.)

The Wild Dutchman mine is a quarter of a mile east of Forest City. It was discovered in 1872 and sold to the Omaha Smelting & Refining Co. of Nebraska, who worked it until September, 1876, when it was leased. (See also p. 263.)

[1] Huntley, D. B., op. cit., p. 441.

Other mines of the American Fork district are:

Mine.	Total length of openings.	Total product to 1880.	Remarks.
	Feet.		
Pittsburg	1,185	2,000 tons	Ore assays 13 ounces silver, 41 per cent lead, and $2 gold.
Sunday	300	$17,000	
Silver Bell	[a]120	130 tons of 100-ounce ore.	
Excelsior Silver Mining Co.			Ore argentiferous galena, assaying 60 ounces silver and 50 per cent lead and a trace of gold.
Utah Consolidated Mining Co.			Seven claims. Several hundred feet of developments.
Queen of the West	1,000		In 1874 $28,000 taken from one pocket.
Orphan		250 tons	Ore assays 60 ounces silver and 40 per cent lead.
Live Yankee and Mary Ellen		600 tons	Ore formerly assayed 18 ounces silver, 7 per cent lead, and $4 gold.
Treasurer	475	A few tons	Ore assayed 85 ounces silver and some lead.
Silver Dipper	600		Ore assays 10 to 20 ounces silver and 40 per cent lead.
Whirlwind	1,000	$3,000	
Noncompromise	400	$15,000	Ore assayed 10 ounces silver.
Hudson		None	An extension of the Pittsburg.

[a] Incline, also some tunneling work.

After the closing of the Miller mine in 1876 assessment work was performed yearly and some ore produced and shipped. In 1904 a body of ore was found in the Miller mine, which during the next few years yielded metals to the value of several hundred thousand dollars, but since 1907 the output has declined.

PRODUCTION.

By V. C. Heikes.

LITTLE AND BIG COTTONWOOD DISTRICTS.

TOTAL PRODUCTION.

The Little Cottonwood district has yielded production of metal annually since 1867 and may be expected to continue productive for many years to come. No complete records were kept of the annual production in the early days, but enough data to make very close estimates possible are found in the statistical reports on mines and mining in the States and Territories west of the Rocky Mountains for the years 1867 to 1876. Between 1875 and 1880 statistics were not compiled by the Government, and for these years the figures in the mining journals and the Salt Lake Tribune are used. The operations and statistics of many of the most prominent producers from 1870 to 1880 were ably reviewed by D. B. Huntley.[1] During the succeeding years the reports of the Director of the Mint give fragmentary figures until the year 1901, and the statistics from that year to the end of 1917 have been compiled by the United States Geological Survey.

In recent years (1901–1917) the most important producers in the Little Cottonwood district have been the Wasatch Mines group, which include the Columbus Consolidated group and the Flagstaff; the Continental-Alta, reorganized as the Unity and later as the Michigan-Utah Mining Co. (includes the early producing claims known as the Darlington, Grizzly, Regulator, and Lavinia); the City Rocks, now part of the Michigan-Utah group (includes the Utah, an early producer); the South Hecla (includes the Alta Hecla, South Columbus, and Wedge); the Emma Consolidated; the Columbus-Rexall, and the Sells.

In the Big Cottonwood district very few properties have in recent years produced any ore. The more productive have been the Black Bess group of the Michigan-Utah Mining Co., the Maxfield, and the Cardiff, which in the last few years has been the largest producer in the region.

It is impossible to segregate the production of the Big and Little Cottonwood districts, and all the available statistics have been combined in the tables below.

J. R. Browne[2] refers to the operation (in 1867) of two small furnaces in Cottonwood Canyon. These furnaces were under construction in 1866, according to the Daily Union Vedette of August 25, 1866, and in September they began producing lead, which evidently was lost in slag and cinders (Vedette, Oct. 26, 1867) and recovered in 1867 by a German metallurgist named Reese under the supervision of A. A. Hirst, who had reconstructed the works for treatment of North Star ores. According to R. W. Raymond[3] the first efficient smelter (a cupola), erected by Woodhull Bros., 7 miles south of Salt Lake City, began to operate in June, 1870, producing 5,000 pounds of bullion in 36 hours. Most of the ore was from the Monitor and Magnet claims. Shipments of ore from the Emma mine (located August, 1868) began in June, 1870, and up to December 31, 1870, Walker Bros. had shipped 4,200 tons of ore (mostly from the Emma, with an average assay of 35 per cent of lead and $182 in silver to the ton).

Lead bullion shipments, mostly from Cottonwood ores, were 2 tons to England and 6½ tons to San Francisco.[4] In the fall of 1870 mining locations in the Big Cottonwood district (the Davenport, Theresa, Wandering Boy, Maxfield, and Prince of Wales) had each yielded some ore for shipment.[5] On the Little Cottonwood side the Emma mine had produced, up to August, 1871, 10,000 to 12,000 tons of ore, which assayed 100 to 216 ounces of silver to the ton and from 30 to 66 per cent of lead, averaging 160 ounces of silver and from 45 to 50 per cent of lead. The total value of the ore, at the cash price paid for it, a large part of it at Liverpool, was about $2,000,000.[6] The Flagstaff mine, up to April, 1871, had yielded over 80 tons of shipping ore.

[1] Huntley, D. B., op. cit., pp. 422–430.

[2] Mineral resources of the States and Territories west of the Rocky Mountains for 1867, p. 485, 1868.

[3] Idem for 1870, p. 223, 1872.

[4] Idem for 1872, p. 319, 1873.

[5] Idem, p. 321.

[6] Idem, p. 323.

Gold, silver, copper, lead, and zinc produced in Big and Little Cottonwood mining districts, 1867–1917.

Period.	Ore mined.	Gold.		Silver.		Copper.		Lead.		Recoverable zinc.		Total value.
		Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	
	Short tons.	*Fine ounces.*		*Fine ounces.*		*Pounds.*		*Pounds.*		*Pounds.*		
1867–1870	5,573	59.90	$1,240	703,138	$933,667			6,444,800	$387,048			$1,321,955
1871–1880	133,796	3,585.02	74,109	6,259,000	7,876,458			95,201,998	5,450,541			13,401,108
1881–1890	22,515	5,426.90	112,184	883,034	927,886			14,784,900	662,998			1,703,068
1891–1900	13,885	7,581.38	156,721	707,731	525,144			8,457,869	323,954			1,005,819
1901	935	161.19	$3,332	37,532	22,519			300,298	12,913			$38,764
1902	850	146.53	3,029	34,120	18,084	58,490	$7,136	272,999	11,193			39,442
1903	1,977	85.24	1,762	69,336	37,441	102,260	14,010	552,483	23,204			76,417
1904	4,878	306.36	6,333	106,249	60,828	235,832	29,479	1,190,005	52,063			148,703
1905	26,003	919.99	19,638	371,683	224,496	811,639	126,616	1,702,258	80,006			450,756
1906	20,801	762.05	15,753	345,102	231,218	1,193,743	230,392	1,922,276	109,570			586,933
1907	19,896	976.93	20,195	399,417	263,615	1,074,238	214,848	2,337,924	123,910			622,568
1908	5,866	321.36	6,643	63,246	33,520	269,212	35,586	603,840	25,362			101,061
1909	13,208	335.72	6,940	158,867	82,611	1,842,711	239,553	332,475	14,296			343,400
1910	14,203	381.87	7,894	202,010	109,085	804,018	102,110	1,102,907	48,528			267,617
1901–1910 [a]	108,617	4,427.24	91,519	1,787,562	1,083,417	6,392,143	999,680	10,317,465	501,045			2,675,661
1911	6,040	139.17	2,877	158,448	83,978	407,719	50,965	1,043,608	46,963			184,783
1912	6,566	142.46	2,945	186,183	114,503	386,963	63,849	1,135,191	51,084			282,381
1913	5,167	112.08	2,317	93,821	56,668	136,901	21,219	1,091,617	48,031			128,235
1914	12,583	372.22	7,695	242,825	134,282	214,971	28,591	2,887,109	112,597	8,804	449	283,614
1915	24,590	430.37	8,897	445,111	225,671	334,944	58,615	12,263,403	576,380	229,663	28,478	898,041
1916	41,960	1,035.90	21,414	755,980	497,435	819,192	201,521	15,061,273	1,039,228	60,746	8,140	1,767,738
1917	48,203	900.33	18,611	917,512	756,030	1,163,084	317,522	11,927,552	1,025,770	21,721	2,216	2,120,149
1911–1917	145,109	3,132.52	64,756	2,799,880	1,868,567	3,463,774	742,282	45,409,753	2,900,054	320,934	39,283	5,614,942
1867–1917	429,495	24,213.05	500,529	13,140,345	13,215,130	9,855,917	1,741,962	180,616,785	10,225,640	320,934	39,283	25,722,553

[a] Within the period covered by this total the Columbus Consolidated Co. operated its concentration mill from 1904 to 1912, inclusive, producing 15,172 tons of copper-lead concentrates. In 1905 the Continental Alta produced lead concentrates, and in 1910 some copper-lead concentrates were recovered from Columbus Extension ores.

Between 1871 and 1880 the largest producers were the Emma (largely depleted by 1873), Flagstaff, North Star, Vallejo, Joab Lawrence Co., City Rocks, Grizzly and Lavinia, Davenport, Savage and Montezuma, Reade & Benson, and Prince of Wales. According to Huntley,[1] the Emma mine had yielded, to June 1, 1880, ore aggregating 27,451 tons, for which $2,637,727 was received. The rich ore bodies of the Flagstaff mine gave out in December, 1873, having produced about 31,000 tons, which probably assayed $10 in gold and 60 ounces of silver to the ton and 40 per cent of lead and which sold for $80 a ton. Between 1874 and 1879 about 69,000 tons of ore was produced from the Flagstaff, probably assaying $4 in gold and 30 ounces of silver to the ton and 20 per cent of lead, and was sold for $30 a ton, aggregating from the beginning about $4,550,000.[2] The Prince of Wales and Antelope groups of claims were discovered about 1870 and had a record of producing over $1,000,000 to the end of 1884.[3] Subsequent records of the Prince of Wales in the reports of the Director of the Mint to 1890 show not over 10,121 tons of ore shipped, averaging probably 105 ounces of silver to the ton and 30 per cent of lead.

The Flagstaff produced between 1881 and 1890, the Joab Lawrence or Vallejo and City Rocks almost continuously to 1891, and the Maxfield was the heaviest shipper in the years 1884, 1887, 1888, and 1890. In 1891 and 1892 the Maxfield and Flagstaff were the principal producers. Between 1891 and 1900 very little or no mention of these districts was made in the reports of the Director of the Mint. The figures given in the table are differences between the known output of the other districts in Salt Lake County and the total for the county as given by the Director of the Mint in the reports for each year.

PRODUCTION, BY ORES.

The character of the ores produced and the average metal content and average value are shown in the following descriptions and tables.

Dry or siliceous ores.—The dry or siliceous ores shipped to smelters from the Big and Little Cottonwood districts comprise gold and silver ores carrying copper and lead sulphides too small in amount to be of value. The contributors of the dry or siliceous ores in 1903 and 1909 were the Scottish Chief, Dipper, Big Mitt, Columbus Extension, Noah, Red Bell, Alta Michigan, Alta Utah, Old Emma, Alta Wasatch, and Morning Star.

Siliceous ore, with average metallic content, produced in Big and Little Cottonwood districts and shipped to smelters, 1903, 1909, 1914–1917.

Year.	Ore (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
1903	104	$0.79	22.09	......	1.63	$14.10
1909	10	36.80	.30	1.17	......	40.20
1914	67	3.99	4.84	1.54	1.95	8.94
1915	None.	......	......	......	......	......
1916	38	.84	2.47	1.34	1.93	11.71
1917	9,120	.17	41.26	.12	3.13	40.19

Copper ore and concentrates.—The copper ores and concentrates include those carrying over 2.5 per cent of copper. Shipments were made most frequently by the City Rocks, Columbus, and Cardiff properties, and less frequently by the Wasatch-Utah, Alta Hecla, South Columbus, South Hecla, West Columbus, Blue Point, Copper Apex, Mountain Lake, Iowa, Consolidated Jefferson, Columbus Extension, White Captain, Alta Emerald, Carbonate, Morning Star, Big Cottonwood, Great Western, South Hecla Extension, Evergreen, Woodlawn, Columbus-Rexall, and Alta Consolidated.

Copper ore and concentrates, with average metallic content, produced in the Big and Little Cottonwood districts and shipped to smelters, 1903–1917.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
Crude ore.						
1903	30	$2.40	32.10	11.00	1.25	$50.17
1904	30	.70	23.60	14.15	......	50.60
1905	2,743	4.22	67.29	6.41	1.54	66.70
1906	3,608	2.04	44.06	6.93	2.58	61.70
1907	207	1.14	18.61	8.03	3.16	48.88
1908	214	20.83	11.05	4.42	1.46	39.59
1909	9,907	.54	12.24	8.22	.03	28.30
1910	2,463	1.49	24.79	9.05	.08	37.94
1911	1,356	.65	26.72	7.85	......	34.43
1912	813	.68	20.89	5.27	......	38.96
1913	328	.53	35.68	6.70	......	42.84
1914	165	.61	58.54	7.75	......	53.60
1915	134	1.19	20.58	9.14	.35	43.95
1916	170	1.12	2.54	6.01	......	32.37
1917	3,374	.87	9.64	7.23	......	48.29
Concentrates.						
1909	152	0.36	13.54	9.67	......	32.55
1911	8	10.62	1.87	7.90	......	31.37

[1] Huntley, D. B., op. cit., pp. 423, 424.

[2] Idem, p. 428.

[3] Rept. Director of the Mint upon production of precious metals, 1884, p. 421, 1885.

Lead ore and concentrates.—In general the crude lead ores and concentrates are those containing over 4.5 per cent of lead. Shipments were made most frequently during the last decade by the Maxfield, Columbus, Emma, Albion, Golconda, Cardiff, and Flagstaff, and less frequently by the North Star, Caledonia, Cabin, Silver King, Alta Consolidated, Michigan-Utah, Carbonate, South Hecla, Sells, Continental Alta, City Rocks, Columbus Wedge, Black Bess, Columbus Extension, Reed Peak, West Toledo, Hayes, Scottish Chief, Phoenix, Copper Apex, Carbonate, Silver Mountain, South Columbus, Frederick, Progress, East Columbus, Baby McKee, Prince of Wales, Wasatch Mines, Alta Hecla, Howell, Alta-Tiger, Democrat, Woodlawn, Peruvian, and Highland Chief

Lead ore and concentrates, with average metallic content, produced in Big and Little Cottonwood districts and shipped to smelters, 1903–1917.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
Crude ore.						
1903	977	$1.03	55.50	2.51	16.41	$51.67
1904	2,975	1.84	28.28	2.30	16.49	38.31
1905	6,724	.88	14.56	.84	25.02	35.91
1906	558	2.59	19.98	.75	16.04	37.35
1907	1,708	.96	17.27	1.13	16.36	34.24
1908	687	.97	23.66	.82	16.17	29.25
1909	191	.70	28.30	1.71	25.11	41.44
1910	447	.70	33.83	.40	15.82	36.62
1911	2,213	.53	28.58	1.04	15.53	32.25
1912	1,945	.32	40.35	1.84	15.12	44.82
1913	3,918	.37	15.12	.16	11.87	20.45
1914	1,607	.61	18.30	.53	11.82	21.37
1915	23,720	.37	18.29	.59	25.75	35.94
1916	32,368	.52	20.13	.62	21.43	46.34
1917	35,185	.39	14.06	.86	15.98	44.16
Concentrates.						
1905	2,763	$0.13	11.44	1.41	4.88	$16.10

Copper-lead ore and concentrates.—Copper-lead ore and concentrates are classified in the same way as copper and lead ores. Shipments were made most frequently during the last decade by the Columbus, Continental Alta, South Columbus, City Rocks, Alta Consolidated, Michigan-Utah, Prince of Wales, Copper Apex, Gypsy Blair, Caledonia, Columbus Extension, Wasatch Mines, Alta Utah, Columbus-Rexall, and Henefer.

Copper-lead ore and concentrates, with average metallic content, produced in Big and Little Cottonwood districts and shipped to smelters, 1903–1917.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
Crude ore.						
1903	866	$0.82	16.60	3.40	15.40	$32.04
1904	844	.88	18.11	4.23	7.20	28.40
1905	112	.55	16.37	4.35	10.73	34.20
1906	4,336	1.06	31.68	4.98	8.66	51.68
1907	7,413	2.05	38.49	4.93	6.48	54.00
1908	1,149	.66	18.93	6.56	6.57	33.54
1909	857	.94	25.75	6.58	8.65	38.88
1910	1,961	.66	31.32	5.09	9.86	39.18
1911	1,120	.33	44.56	5.29	13.86	49.64
1912	2,093	.80	31.09	4.05	11.00	43.19
1913	890	.77	25.65	4.51	8.93	38.09
1914	727	.39	28.06	4.40	9.73	35.34
1915	204	.22	38.04	6.24	9.50	50.28
1916	7,168	.36	13.63	2.65	6.65	31.56
1917	486	.47	27.74	5.12	10.75	69.81
Concentrates.						
1904	275	$0.37	22.28	3.45	15.93	$35.82
1905	2,956	1.44	27.89	4.38	10.34	41.83
1906	3,249	.73	11.57	3.90	12.41	37.80
1907	3,216	.97	25.10	4.23	12.51	47.72
1908	1,090	.69	20.95	4.04	10.27	31.08
1909	438	.56	18.13	7.50	9.32	37.49
1910	2,152	.34	28.88	3.60	13.27	36.75
1911	291	.26	31.00	5.04	7.88	36.39
1912	426	.05	35.23	7.06	10.19	54.19
1915	21	.52	23.76	4.90	7.13	36.48

Zinc ore.—There is zinc ore of shipping grade in the Carbonate mine in the Big Cottonwood district and in the Wasatch mines at Alta. Shipments were made from the former in 1916. Lessees on the Albion dump at Alta have shipped some zinc concentrates. The output shown below came largely from the Carbonate mine. The Columbus-Rexall and Wasatch mines each produced a carload in 1915.

Lead-zinc ore.—Lead-zinc ore was shipped in small quantity from the Albion in 1917 and from the Woodlawn in 1915 and 1916.

Zinc ore, with average metallic content produced in Big and Little Cottonwood districts and shipped to smelters, 1914–1917.

Year.	Quantity (short tons).	Silver (ounces per ton).	Lead (per cent).	Recoverable zinc (per cent).	Average gross value per ton.
1914	17			25.89	$26.41
1915	437			25.70	63.74
1916	94	6.91	2.08	23.59	70.65
1917	9			26.23	53.55

DIVIDENDS.

Dividends aggregating several million dollars are reported to have been paid to stockholders by mining companies operating in the Little Cottonwood and Big Cottonwood districts. Some of the published statements follow, but many of them are discredited by old residents, who say that the early managements were very expensive. Raymond [1] gives a statement furnished by N. M. Maxwell, superintendent of the Flagstaff mine, as follows:

The product of the Flagstaff furnaces during 1872 was 3,000 tons of metal, containing

Silver......	\$390,000; average per ton,	\$130
Gold........	120,000; average per ton,	40
Lead........	240,000; average per ton,	80
	750,000	

The capital of the company is £300,000, on which 30 per cent in dividends have been paid during the last three months and 24 per cent during those preceding, the total amount of dividends paid being £76,000.

In a later report [2] Raymond says:

This splendid mine has produced during 1873, according to the directors' report, 15,000 tons of ore of an average value of \$54 per ton in the ore market. The same report says the expenses for mining ought to have been \$5, hauling \$8, establishment charges \$4, total \$17, leaving \$37 profit per ton. Yet there was not only no profit made, but in the fall the company was very heavily in debt and the value of shares depreciated rapidly in London.

According to Huntley,[3] who reviews conditions in the district up to October, 1880, the Emma mine, worked by English managers, paid \$300,000 in dividends (one authority says \$1,300,000) until September, 1874, when it was attached for an indebtedness of \$300,000. It was then idle until October, 1877. The Flagstaff mine, when owned by the English company, paid dividends that amounted to about \$350,000.

From all available data the dividends paid by the mining companies in the Little and Big Cottonwood districts to the end of 1917 are as follows: Emma, \$300,000; Flagstaff, \$350,000; Columbus Consolidated, \$212,623; Vallejo and Titus (Joab Lawrence), \$180,000; Maxfield, \$118,000; Cardiff, \$625,000; South Hecla, \$39,450. If \$700,000 is estimated to cover the dividends realized from other properties, including the Prince of Wales, the total dividends exceed \$2,500,000.

AMERICAN FORK DISTRICT.

The American Fork district was organized July 21, 1870, but work was not commenced to any extent on the mining claims until the fall of that year. The Miller mine, discovered in September, 1870, was the principal producer. In 1871–72 the Sultana smelter was built for the reduction of Miller ore and ran irregularly until the spring of 1875. The Miller ore bodies gave out and the mine was closed in December, 1876. It was in the hands of lessees at different periods to the end of 1880. D. B. Huntley [4] estimates the production of ore from the Miller mine to the end of 1880 between 13,000 and 15,000 tons, assaying from 40 to 54 per cent of lead and 30 to 47 ounces of silver and \$2 to \$10 in gold to the ton. In 1872 the Wild Dutchman mine was discovered and worked by the company until September, 1876, when it was leased. Its total production to 1880 was estimated at 7,900 tons of ore, averaging 45 ounces of silver to the ton and 40 per cent of lead. The Pittsburgh, Sunday, Silver Bell, Orphan, Queen of the West, Live Yankee, Whirlwind, Noncompromise, and, in the Silver Lake section, the Milkmaid and Wasatch King, were producers prior to 1880.

During the period 1881–1890 development work was done, but very little ore was shipped, probably not averaging over 100 tons a year. The aggregate shipments of the Bellerophon, Live Yankee, Milkmaid, Miller, Silver Bell, Sultana, Wild Dutchman, and E. H. Bailey & Co. in 1886 amounted to 80½ tons.[5]

In 1891 the Wild Dutchman, North Star, Kalamazoo, and Live Yankee properties yielded an aggregate of 100 tons of ore.[6] Estimates were made for the remaining years of this decade, and it is presumed that the average ore yield was not greater than in 1891.

For the period 1902 to 1917, inclusive, the figures of production were collected by the Survey; those for the year 1901 are estimated from the best records available.

The total ore mined between 1870 and 1880 is estimated at 39,950 tons; 1881–1890, 990 tons; 1891–1900, 1,000 tons; and 1901 to 1917, 22,277 tons, making the total output of ore

[1] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1872, p. 247, 1873.
[2] Idem for 1873, p. 260, 1874.
[3] Huntley, D. B., op. cit., p. 423.
[4] Idem., p. 444.
[5] Director of the Mint Rept. upon production of precious metals, 1886, p. 224, 1887.
[6] Idem, 1891, p. 224, 1892.

Gold, silver, copper, lead, and zinc produced in American Fork district, 1870–1917.

Period.	Ore.	Gold.		Silver.		Copper.		Lead.		Recoverable zinc.		Total value.
		Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	Quantity.	Value.	
	Tons.	*Fine ounces.*		*Fine ounces.*		*Pounds.*		*Pounds.*		*Pounds.*		
1870–1880	39,950	3,116.10	$64,415	1,377,600	$1,683,542			14,868,000	$882,744			$2,630,701
1881–1890	990	526.80	10,890	32,475	34,071			693,000	30,405			75,366
1891–1900	1,000	200.00	4,134	22,000	15,876			510,000	17,655			37,665
1901	128	35.40	732	3,508	2,111			76,800	3,302			6,145
1902	39	3.53	73	663	351			23,666	970			1,394
1903	64	21.28	440	1,872	1,011			11,214	471			1,922
1904	922	800.00	16,537	18,880	10,809			617,280	27,006			54,352
1905	2,479	1,301.00	26,894	27,740	16,755	88	$14	1,374,660	64,609			108,272
1906	2,914	2,096.82	43,345	47,611	31,899			1,959,784	111,708			186,952
1907	4,706	3,483.80	72,017	93,551	61,744	45,098	9,020	3,612,785	191,478			334,259
1908	2,356	745.52	15,411	64,840	34,365	26,073	3,442	1,386,596	58,237			111,455
1909	1,025	125.13	2,587	39,821	20,707	10,670	1,387	628,148	27,011			51,692
1910	965	183.12	3,785	34,204	18,470	12,227	1,553	519,749	22,869			46,677
1901–1910	15,598	8,795.60	181,821	332,690	198,222	94,156	15,416	10,210,682	507,661			903,120
1911	494	79.05	1,634	9,441	5,004	4,092	511	386,544	17,394			24,543
1912	659	121.44	2,510	11,172	6,871	3,466	572	380,630	17,128			27,081
1913	411	30.61	632	6,609	3,991	2,949	457	279,772	12,310	2,712	$152	17,542
1914	224	68.93	1,425	4,189	2,316	3,591	478	106,219	4,143	14,830	757	9,119
1915	413	49.03	1,013	8,039	4,076	4,018	703	259,499	12,196	2,050	254	18,242
1916	868	43.25	895	48,360	31,821	31,189	7,673	250,460	17,282	27,319	3,661	61,332
1917	3,610	96.94	2,004	35,021	28,857	15,630	4,267	641,990	55,211			90,339
1911–1917	6,679	489.30	10,113	122,831	82,936	64,935	14,661	2,305,114	135,664	46,911	4,824	248,194
1870–1917	64,217	13,127.80	271,373	1,887,596	2,014,647	159,091	30,077	28,586,796	1,574,129	46,911	4,824	3,895,050

64,217 tons. This figure, used in seeking the average of the ore produced, gave $4.40 in gold and 29.43 ounces of silver to the ton and 23.05 per cent of lead, and, in value, including small quantities of copper and zinc, $60.73 to the ton.

ORE DEPOSITS.

By B. S. Butler.

DEVELOPMENT.

As in most other mining districts, the earliest development work on the ore bodies consisted in following them down with shafts or inclines. The large flows of water frequently encountered at relatively shallow depth, the heavy cost of pumping, and the strong relief of the region, however, soon led to the driving of tunnels, which have been carried to increasing depths; and in recent years the tendency has been toward the consolidation of properties into large groups and their development by deep drainage tunnels.

The strong relief of the region makes it especially adapted to exploration by tunnel, and there can be no question that this is the most practical method of development. The great abundance of "fine tunnel sites" has apparently been a temptation that was hard to resist, as is shown by the scores of tunnels that have been started. That more than a "site" is necessary to success, however, is indicated by the many failures.

CLASSIFICATION.

All the deposits of proved commercial importance are in the sedimentary rocks, though some small veins in the intrusive rocks have been prospected and a little ore has been shipped from them. The deposits in the sedimentary rocks can be referred to three general classes, but the assignment of deposits to these classes is not always easy, as they show transitions. The main classes recognized are contact deposits and deposits associated with fissures in the sedimentary rocks. The deposits associated with fissures are all related but may readily be separated into fissure deposits and bed deposits. Deposits associated with thrust faults may be regarded as a particular type of bed deposit.

VEINS IN INTRUSIVE ROCKS.

The intrusive rocks of the Little Cottonwood and Alta-Clayton Peak stocks have been much jointed and in places sheared and crushed, and over considerable areas have been mineralized along the joints. The weathering of the sulphides stains the rocks with oxide of iron. Such staining is notable in the Little Cottonwood stock from White Pine Gulch eastward for a mile or more, and in many localities in the Alta-Clayton Peak stock. Pyrite is the most abundant mineral in the veins in the intrusive rocks, but chalcopyrite, galena, and molybdenite are present.

The Alta-Gladstone vein, about 2 miles southwest of Alta, in the Little Cottonwood stock, consists mainly of coarsely crystalline quartz, pyrite, molybdenite, and a little white carbonate, probably calcite. The coarsely crystalline quartz is strongly suggestive of pegmatite, though neither feldspar nor muscovite was recognized as a vein mineral. The wall rock is altered to an aggregate of quartz and muscovite, in which sulphides are disseminated. In the vein the sulphides show a tendency to segregate. In the portion accessible at the time of visit the vein material along one wall consisted largely of coarsely crystalline pyrite, and the remainder contained molybdenite with the gangue minerals and some pyrite.

Small veins containing molybdenite are reported from several places in the Little Cottonwood stock but have been only slightly prospected. In White Pine Gulch veins containing pyrite, galena, sphalerite, and chalcopyrite in a quartz gangue have been prospected. The largest vein seen was about a foot thick and could be traced for 300 to 400 feet.

On the South Fork of Little Cottonwood Creek the intrusive rock is cut by east to northeast joints and fissures, carrying quartz-sulphide veins. Pyrite is the most abundant sulphide, but some galena is present. Similar veins occur in the intrusive rocks around the head of Big Cottonwood Canyon, though copper appears to be more abundant in this section. Some of the rocks south of Silver Lake show a rather pronounced copper stain which has resulted from the oxidation of sulphide veins along the joints.

CONTACT DEPOSITS.

The bodies of limestone adjacent to the intrusive rocks that have been most prospected are those which contain abundant magnetite. These contain variable but usually small amounts of iron and copper sulphide and some gold and silver. The production from these

deposits has so far been small, as most of the material is of too low grade to be profitably mined and shipped under ordinary conditions with the available transportation facilities.

Contact deposits containing a high percentage of iron have been developed in the Michigan-Utah, Alta Consolidated, and South Hecla mines, and some ore has been shipped from them. Such deposits have been prospected around the head of Little Cottonwood Canyon on both sides of the Alta-Clayton Peak stock and at the head of Big Cottonwood Canyon, especially around the head of Dog Lake canyon and across the divide in Snake Creek canyon. Some of the deposits in Dog Lake and Snake Creek canyons contain abundant ludwigite and forsterite. Near Dog Lake they contain abundant magnetite. Bornite appears to be the principal original sulphide, though chalcopyrite is present and in some places may be more plentiful than bornite.

The Steamboat mine, which is developed by a tunnel extending from Snake Creek toward the head of Big Cottonwood canyon, contains some copper ore in which forsterite is an important gangue mineral and chalcocite is the principal sulphide. In the hand specimen the relation of the forsterite and chalcocite strongly suggests that the sulphide is primary, but microscopic examination shows it to contain remnants of bornite which indicate that it has replaced that mineral. In some specimens collected from the dump and said to come from the same part of the mine as those containing the chalcocite, the bornite has been partly replaced by chalcopyrite. In this deposit, as in those near Dog Lake, bornite appears to have been the important primary sulphide.

As has been stated in the discussion of the contact alteration of the limestone the evidence seems to point to solutions given off by the igneous magma as the source of the metallic and some of the nonmetallic constituents of the deposits.

FISSURE DEPOSITS.

GENERAL CHARACTER.

In the fissure deposits the minerals occur mainly as a filling of fissures. In nearly all there is some replacement of the wall rock, and in some the replacement is so extensive at certain points that the deposit approaches the bed type. In others contact minerals are present in the replaced wall rocks, and the deposits approach the contact type. The fissure deposits are found at different stratigraphic horizons, but where the adjacent rock is especially susceptible to replacement, either on account of its chemical composition or of its physical character, they give place to bed deposits. In several places the limestone adjacent to fissures has been strongly brecciated and the breccia has been partly replaced by ore minerals, forming a deposit intermediate between fissure and bed deposits. Most of the fissure deposits strike northeast and east-northeast and have steep northwesterly dips, but a few strike nearly due north. They occur in rocks of very different character and composition, including the Cambrian and pre-Cambrian quartzites and shales, in which the Toledo, American Consolidated Copper (Branborg), Cardiff (upper tunnel), Pacific, and one of the Live Yankee veins occur; the Paleozoic limestone, which is the predominant wall rock in the Michigan-Utah and Prince of Wales mines; and even the Thaynes formation (lower Triassic), in which the vein-like body of the Barry-Coxe mine is located. The Dutchman, Bay State, and two of the Live Yankee veins are in early Paleozoic, probably Cambrian limestone.

VEINS IN BIG AND LITTLE COTTONWOOD DISTRICTS.

Toledo vein.—The Toledo vein was not being worked at the time of the writer's examination. The following description of the vein is given by Huntley:[1]

> The ore occurs in a fissure vein, from 1 to 3 feet wide, cutting diagonally across a quartzite formation, dipping 80° NNW., and is found in several chimneys 50 feet long on the strike and about 50 feet apart. They dip with the strike toward the east. The ore is a hard, porous brown siliceous oxide of iron of very high grade. It was said to have averaged from 80 to 109 ounces to the ton. Water was found 200 feet from the surface, but the character of the ore did not change. Where the vein passed from the quartzite into a belt of schist there was much pyrite. The mine is operated through a shaft 455 feet deep, vertical for part of its length. The horizontal development of the vein is 350 feet, and the total cuttings are estimated at 2,000 feet.

Grizzly and City Rocks fissures.—The deposits associated with the Grizzly and City Rocks fissures in the territory of the Michigan-Utah Consolidated Mining Co. may be classed as fissure deposits, though in places they ap-

[1] Huntley, D. B., op. cit., p. 425.

proach the bed deposits in character. The sedimentary rocks consist mainly of Paleozoic limestones. Cambrian limestone has been thrust over Carboniferous rocks, as shown on the map (Pl. XXVII). The sedimentary rocks are cut by several northeast fissures that dip steeply northwest, of which the Grizzly and City Rocks fissures are the most prominent. Several dikes have the same general strike as the fissures; a dike of white granite porphyry follows the Grizzly fissure for a considerable distance and forms one wall of the ore bodies, and other dikes of monzonitic or dioritic composition are exposed at the surface and are cut in the workings.

Certain beds cf the limestone, where crossed by the dikes and fissures, have been strongly brecciated, and the limestone has been brecciated along the thrust faults. Some mineralization occurs all along the fissures but is by far the most extensive in the brecciated limestone, where it forms the more valuable ore shoots. The larger shoots, therefore, roughly follow the intersections of certain beds of limestone and the fissures, or the intersections of the thrust-fault planes and the fissures. The fissures have been followed through the ridge between Little Cottonwood Canyon and Honeycomb Fork; and the City Rocks fissure is cut by the Lake Solitude tunnel near the head of Solitude Fork, about 300 feet below the Cleve tunnel, and has been developed by a winze sunk 200 feet below the Lake Solitude tunnel level. A raise connects the Lake Solitude and Cleve tunnels.

The ore is largely oxidized to the Lake Solitude level and is said to be oxidized to the bottom of the winze. There are, however, remnants of sulphide even near the surface. The metals present in commercial quantity are lead, silver, and copper, with a little gold. Limonite is abundant, manganese oxide locally plentiful, and wulfenite present in notable amounts. A little manganese ore has been shipped, principally from the Stewart vein. Huntley[1] describes the upper portion of what is probably now known as the Grizzly fissure as follows:

The Utah is a fissure vein, from 1 foot to 20 feet wide, dipping 70° or more NW. through strata of blue and white siliceous limestone or dolomite, which dip about 30° NE. It had outcrops in places and is known to extend 4,000 feet in length and 700 feet in depth. The gangue of the vein is oxide of iron and a sand, apparently the result of the decomposition of the siliceous country rock. The ore is from 1 foot to 10 feet (averaging from 2 to 3 feet) wide, immediately in contact with the walls but not confined to either. Three chimneys have been found 200 feet long and about 300 feet apart. One came to the surface, and the others to within 100 feet of it. They dip with the strike about 65° NE. The positions of these chimneys appear to be determined by the strata of white limestone. The ore makes where the vein crosses the white limestone but pinches where the harder blue limestone is encountered. It is a soft red, sometimes rather sandy oxide of iron containing carbonate of lead and galena and in places stains of malachite. The first class assays 30 per cent lead, 30 ounces and upward of silver, and a trace of gold. There is also much low-grade jigging ore in the mine. On the south side a dike of porphyry appears, running nearly parallel with the vein. Near the porphyry the ore has not been so rich.

Honeycomb Fork.—Huntley[2] describes the mines on Honeycomb Fork as follows:

The Butte mine, at the head of Honeycomb Fork, 2½ miles northeast of Alta, was discovered in 1869 and has been worked irregularly since. It is said to be a fissure vein in limestone, from 6 inches to 4 feet wide, dipping 55° N., and is supposed to be an extension of the Utah and City Rocks of Little Cottonwood district. It outcropped for several hundred feet on the hillside in the form of a soft ocher-stained limestone. Ore occurs on the footwall in 8 or 10 lenticular bodies, from 1 inch to 3 feet wide, at considerable distance below the surface. It is a high-grade ocher and carbonate. Sometimes much black oxide of manganese is found. The mine is dry (excepting surface water) and is worked through a 200-foot tunnel. * * * The total product to June 1, 1880, was estimated at $27,000.

The Oregon is an extension of the Butte. The property also includes four patented prospects on which very little work has been done—the Columbus, the Taylor, the Abbey, and the Black Bess. It is a fissure vein, from 1 to 15 feet (average, 3 feet) wide, dipping 60° NNE. in limestone. Only one body of ore has been found. This came to the surface and was 120 feet long, from 3 inches to 3 feet wide, and extended to a depth of 300 feet. It assayed about 50 ounces silver and 30 per cent lead. * * * Water was found at 100 feet, but no change occurred in the oxidized character of the ore. * * * The total product to 1880 was estimated at $10,000.

Savage and Montezuma claims.—Raymond[3] describes the mineralization in the Savage and Montezuma claims as follows:

Savage: The ore shows near the entrance of the incline as a rusty, gossan-like mass or vein, cutting the beds of limestone vertically. A few feet below the surface, within the incline, the thickness of the vein overhead is about 3 feet. It pinches up at a point lower down and toward the bottom of the incline opens out again to a vein from 2 to 3 feet wide of rich ore, yellowish and rusty in color

[1] Huntley, D. B., op. cit., p. 425.

[2] Idem, p. 428.

[3] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1871, p. 324, 1872.

and in places streaked with green stains of copper. Quartz vein stone is found at the bottom of the mine, and it is hoped that this will prove to be a continuous, regular vein formation. The ore is soft and earthy, much like that from the Emma and other claims. It is rich in silver and lead. The mineral wulfenite is found disseminated in small, thin crystals throughout the vein.

The Montezuma is about 90 feet west of the dump of the Savage. The vein is vertical, or nearly so, like the Savage, and extends apparently from 3° to 5° west of north (magnetic). The croppings are rusty and rather hard, but below the ore is softer and richer in silver and lead. The country rock is a hard black limestone. * * * The vein may be said to average, where opened, 2½ feet in thickness.

Cardiff vein.—The vein of the Cardiff mine, exposed in the upper tunnel, follows a fissure that strikes N. 35° E. and dips 65° NW. The wall rock is the "overthrust quartzite" above the Alta overthrust. The ore consisted of pyrite and tetrahedrite and a minor amount of galena in a quartz gangue. No zinc blende was noted, but a qualitative test proved the presence of a little zinc in the tetrahedrite. No zinc blende was detected by microscopic study. Tetrahedrite containing a notable amount of zinc has been reported from the Park City district. The ore minerals formed apparently pure bands or lenses 1 to 6 feet thick, separated by bands of white quartz and unreplaced quartzite. The ore mined was said to contain about 12 per cent of copper, a good proportion of silver, and \$1 to \$2 in gold to the ton. The galena was said to increase above the upper tunnel and, locally at least, to mark the upward termination of pay ore. The ore was practically free from oxidation at and below the level of the upper tunnel. At higher levels, in a vein on which the old Cardiff shaft was sunk, lead carbonate ore was found down to a depth of 150 feet below the shaft collar. The large ore body which furnishes the present output belongs to the thrust-fault type of deposits. (See p. 281.)

Veins on American Consolidated Copper Co.'s property.—The American Consolidated Copper Co.'s (Branborg) property contains three fissures—the Garfield, Silver King, and Gustavus Adolphus—all striking N. 35°-40° E. and dipping about 60° NW. Another fissure, probably a branch of the Garfield, strikes N. 10° E. and dips about 60° W. The Garfield fissure and its branch carry ore containing pyrite, blende, and galena in a quartz gangue. They have been cut by a long adit, and the Garfield fissure has been followed by drifts to the southwest and northeast. Northeastward it pinches at the quartzite and shale contact. No prospecting for a continuation of the fissure in the limestone above the shale has been undertaken. Shallow pits in the limestone, however, have struck small quantities of lead carbonate with a high silver content, which may be connected with northeasterly fissures.

The Silver King fissure was cut by the tunnel 1,200 feet from the portal. At the time of visit, in the summer of 1916, a short drift exposed vein quartz and a little sulphide.

The Gustavus Adolphus fissure has the same type of mineralization, but its ore contains less zinc and more silver than that from the Garfield fissure. Small amounts of oxidized ore mined from shallow workings are said to have yielded 1,000 ounces of silver to the ton, but the oxidized ores are very superficial and almost negligible.

Howell mine.—The Howell mine is developed on a fissure in the Cambrian quartzite that strikes about N. 30° E. and dips steeply northwest. This fissure has been followed along the strike for several hundred feet. The ore has apparently formed as shoots in the fissure. At several points ore has been stoped from shoots. The original minerals consisted of quartz and sulphides of iron, lead, zinc, and copper.

Barry Coxe mine.—The ore deposits in the Barry-Coxe mine, on the southwest slope of Scott Hill, are transitional between the contact and fissure types of deposits, also between the fissure and bed replacement types. The ore, so far as developed by shallow workings in 1912, occurs as pockets in partly metamorphosed limestone along fissures trending N. 13° W. north and east. The pay ore is found between layers of lean silicate rock and replaces the walls for a few feet from the fissure. The most pronounced replacement exposed at the time of examination extended 10 feet from the N. 13° W. fissure. The ore seen was a mixture of pyrite, blende, and galena in a gangue consisting essentially of garnet, diopside, sericite, and quartz. One of the easterly fissures, along a fault plane against which the ore along a northerly fissure stopped, contained green copper stains. The garnet and diopside were formed before the ore and other gangue min-

erals, but there is no evidence to determine whether the country rock was first partly replaced by contact-metamorphic minerals and at a distinctly later period replaced further by the ore, or whether all the minerals were deposited in definite sequence during one period. Absence of fracturing in the metamorphic minerals favors the latter view.

VEINS IN AMERICAN FORK DISTRICT.[1]

Silver Dipper vein.—The Silver Dipper vein follows a fissure that strikes N. 65° E. and dips 60°-65° NW. in Cambrian quartzite. The vein, which was worked in the seventies, is said to have consisted of pyrite and quartz with some good shoots of galena.

Waterfall vein.—The Waterfall vein lies along a fault trending nearly due north between shale and quartzite. It is marked by pinches and swells, and the swells are about 4 feet thick. The ore minerals are galena, pyrite, tetrahedrite, and a little zinc blende in a gangue of quartz. The vein has been opened by two tunnels that in 1912 extended northward 50 feet and southward 300 feet from the creek bed.

Live Yankee claim.—Three veins have been worked or prospected on the Live Yankee property, near the head of Mary Ellen Gulch, but only one was accessible in 1912. This vein lies between a footwall of quartzite and a hanging wall of pyritized porphyry and trends N. 85° W. Its ore minerals are pyrite, chalcopyrite, zinc blende, and galena, and its gangue minerals quartz and barite. One of the other veins lies along an east-west fault zone and is said to have contained the "big stope," mined in early days, which is said to have lain between walls of shale at the base of the limestone. Its ore minerals, to judge from specimens on the dump, were chiefly pyrite and chalcopyrite in a gangue of quartz and barite. The gold content is said to have been unusually high, ranging from $20 to $80 or more to the ton. The third vein strikes N. 40° E. in Cambrian limestone but is said to pinch on reaching and following a porphyry dike. Specimens of its ore consist of pyrite, a little chalcopyrite, zinc blende, galena, and jamesonite in a gangue of quartz, barite, and a little ferruginous dolomite. A fourth vein, too small at its outcrop to be of much promise, strikes N. 45° E. in Cambrian limestone and consists mostly of galena in a gangue of dolomite spar. This group of veins differs from those already described in the prominence of chalcopyrite and in a corresponding high gold content. Their mineral and chemical composition, however, show them to be closely related to the other ore bodies of the region, and there is every reason to believe that they were formed at the same time.

Another source of ore on the Live Yankee property has been the glacial drift in the gulch, from which boulders of galena ore have been washed. It is said that in some of the boulders quartzite was attached to the ore, and this may indicate a westward continuation of the N. 85° W. vein, or possibly another vein concealed a short distance up the gulch.

Pacific mine.—A strong vein is being worked in the Pacific (Blue Rock) mine, just south of the southward bend in the American Fork canyon. The vein strikes N. 45° E. in Cambrian quartzite and at one place has a horizontal offset of 18 feet along a N. 70° W. fault. It is 4 to 8 feet in width and has been followed horizontally for about 450 feet, being worked through the lower tunnel of the mine. Below the tunnel its dip is 60° NW. Above the tunnel the dip flattens and the vein narrows upward until it coincides with a bedding plane at or near the shale contact. In the southern part of the mine the ore is continuous from the shale contact, 130 feet up the dip from the tunnel, to and beyond the lowest workings, 70 feet down the dip from the tunnel. The pay ore pinches northward as well as upward. The ore consists of galena and pyrite in a gangue of quartz and barite. The galena diminishes upward, and near the shale contact granular pyrite is the only ore mineral. The barite tends to be localized in lenticular shoots. The ore is in part of milling and in part of shipping grade.

The old workings of the Pacific mine have found showings of ore but were inaccessible in 1912. Oxidized ore rich in silver from a small inclined shaft north of the main workings contains green stains, locally called "bromides," but proved by chemical tests to be the copper carbonate, malachite.

Utah Centennial claims.—The main vein of the Utah Centennial property, southeast of

[1] The descriptions of mines in the American Fork district are by G. F. Loughlin.

Pittsburg Lake, trends about east and shows some lead ore at the outcrop. In 1912 two tunnels were being driven to reach this vein. The eastern tunnel starts in quartzite at the upper road in a north-northeast direction and follows a narrow vein of white quartz with some pyrite and a few small pockets of galena. The tunnel had penetrated the shale, in which the quartz of the vein has largely disappeared and dolomite and barite have become conspicuous.

Wild Dutchman mine.—Huntley[1] describes the Wild Dutchman mine as follows:

> The ore-bearing formation is a bedded vein, from 3 to 40 feet (average, 20 feet) wide, in dolomite, dipping 40° SE. * * * The gangue in general consists of from 2 to 3 feet of shale upon the footwall and a soft clay containing fragments of silica, and strongly stained by oxide of iron, locally known as "lime porphyry." The ore occurs in scattered egg-shaped bunches of from a few pounds to 600 tons. Five large [ore] bodies have been found, one 20 feet from the surface, one 300 feet from the surface, and the others between these. The ore is the usual ochery carbonate of lead found in a lime formation and contains small amounts of heavy spar. At the water line, in the 450-foot tunnel level, a large body of base ore was found. This consisted of iron and copper pyrites, galena, and a very large percentage of zinc blende. A porphyry dike is said to cut through the footwall into the vein near the large bodies of ore. * * * The total product of the mine is estimated at 7,900 tons, averaging 45 ounces silver and 40 per cent lead.

Dutchman mine.—The principal vein of the Dutchman mine, seen in 1912, is in Cambrian limestone. It strikes N. 40° E. and dips vertically or steeply southeastward. Its width ranges from a mere streak up to 8 feet. Its greatest width is attained in a dark-blue limestone bed which overlies argillaceous beds in the lower part of the Cambrian limestone. The vein, for most of its course, lies along the contact of a narrow porphyry dike. It ends abruptly on the northeast against a dense, blocky argillaceous limestone, which probably marks a northwesterly fault but which could not be studied closely.

A minor vein parallels the main vein. Both have been followed up to the cemented talus that caps the bedrock, and several masses of ore are said to have been found in the talus. The ore mined from both veins is mostly a sandy mixed lead and zinc carbonate. That mined by lessees in recent years is said to average about 30 per cent of lead, 9 to 17 per cent of zinc, and 50 ounces of silver to the ton. Remnants of primary ore are composed of galena and blende in a barite and carbonate gangue. Quartz is inconspicuous.

[1] Huntley, D. B., op. cit., pp. 444-445.

Bay State mine.—The best showings of ore recently reported in the Bay State mine, about midway between the Dutchman and Pacific mines, but on the east side of the canyon, had not been found in 1912. In that year a few small prospect tunnels showed small amounts of galena and barite impregnating a rather light gray limestone, and one showed an interesting occurrence of stibnite. The stibnite, accompanied by barite and a little dolomite, forms small seams or stringers cutting both the limestone and a porphyry dike. Both the limestone and the dike are altered and have a sericitized appearance. The stibnite is partly altered to kermesite, the oxysulphide of antimony ($2Sb_2S_3.Sb_2O_3$), which occurs in tufts of minute red prismatic crystals and probably accounts for all the red staining along the stibnite seams.

BED DEPOSITS.

LITTLE COTTONWOOD DISTRICT.

Occurrence and character of deposits.—The bed deposits have been the most productive of all the types in the Little Cottonwood district, and most of the "bonanzas" that made the district famous in the early days were of this type. Typically these deposits have been formed by the replacement of certain sedimentary beds adjacent to crosscutting fissures. The deposits are thus more or less tabular in form, lie as a whole parallel to the bedding of the sedimentary rocks, and pitch with the intersection of the replaced bedding and the fissures—commonly to the northeast. Where the replacement has extended only a short distance from the fissures the deposits have more nearly the form of "chimneys" than of tabular deposits. The somewhat similar deposits associated with thrust faults are discussed in a later section.

Most of the deposits are oxidized as far down as they have been mined, and it is not possible to determine the original replaced minerals except by scattered remnants of unaltered material. Some deposits that consist largely of sulphide have been developed, notably in the old Emma mine and also in the allied deposits associated with thrust faults, such as the Columbus-Rexall. The original minerals

recognized in the Columbus deposit are pyrite, galena, sphalerite, and tetrahedrite in a gangue of quartz and unreplaced carbonate. Sericitic muscovite also is a common gangue mineral in the bed as well as in the fissure deposits and is prominent both in limestone and shaly beds and in "porphyry."

A specimen of tetrahedrite from the Columbus Consolidated mine was examined by R. C. Wells in the chemical laboratory of the Geological Survey and found to contain 6.24 per cent of lead together with arsenic, as well as antimony. In the material examined no lead mineral other than the tetrahedrite was recognized, and it is believed that the lead is contained in that mineral. Whether or not the tetrahedrite of the district carries lead generally or only at certain localities has not been determined. Specimens of supposed tetrahedrite from the neighboring Park City district have been shown by F. R. Van Horn [1] to contain notable amounts of lead. It has already been noted that tetrahedrite from the Cardiff mine and from the Park City district contains zinc in notable amounts. Probably other minerals will be recognized in the primary ores with more detailed study.

The sulphide ores of the old Emma and Columbus-Rexall mines have not at this writing been examined in detail by the writer. The former consist of pyrite, galena, tetrahedrite or a closely allied mineral, argentite and possibly other silver minerals, and tungstenite in a gangue consisting mainly of quartz and unreplaced and recrystallized limestone. The tungstenite is a new mineral—the first natural sulphide of tungsten [2] whose occurrence has been reported. Pyrite was the earliest mineral to crystallize, and the tungstenite was in part at least later than the galena. The sulphide ore of the Columbus-Rexall consists mainly of pyrite and tetrahedrite with some enargite, galena, and chalcopyrite.

The deposit contains but little nonmetallic gangue. The pyrite was the earliest mineral to crystallize; the other minerals surround the pyrite crystals, giving much of the ore a distinctly porphyritic appearance.

Most of the deposits have been oxidized as far down as they have heen developed. In many places oxidation has extended far below the level of ground water, though it has not been shown to penetrate below the surface drainage, which, because of the strong topographic relief, descends to great depth in the veins that crop out at high elevations. The typical oxidized ore consists of hydrous iron oxides, carbonate and sulphate of lead (cerusite and anglesite), carbonates of copper, and usually manganese oxide.

The ore of several of the mines, notably the Cardiff, Cabin, Alta Consolidated, and South Hecla, contains a large proportion of a basic sulphate of ferric iron, lead, and, in some specimens, copper. This is a yellow earthy mineral that can usually be crushed in the fingers, though some of it forms rather hard lumps, many of which have a core of galena. The mineral has not been quantitatively analyzed but is probably plumbojarosite, with some beaverite and possibly other allied minerals. A massive piece of this ore was sectioned and found to have a core of galena, surrounded and penetrated along cleavage planes by a narrow zone of anglesite, which gives place outward to the yellow mineral with specks of green, possibly malachite. It is evident that in this specimen the mineral has not resulted from the oxidation of a mixture of iron, lead, and copper sulphides, but that the galena has first altered to sulphate and that this has subsequently combined with iron and possibly with copper brought to it in solution. To what extent minerals of this character were present in the large oxidized bodies formerly mined in this district is not known, but published descriptions suggest that they were fairly abundant.

Wulfenite, the molybdate of lead, is rather abundant in the City Rocks vein and in some of the ores from the Alta Consolidated mine, and is present in many of the mines. It is also reported that the ores contain vanadium, but no vanadium-bearing mineral was recognized. Carbonate and silicate of zinc have been recognized in the oxidized ores throughout the district. Considerable zinc from such ores has been produced from the Carbonate mine; and zinc ores have been shipped from the head of Honeycomb Fork and from the Albion mine, in Little Cottonwood Canyon. Sphalerite is rather plentiful in some of the sulphide ores; and it is to be expected that oxidized zinc ores

[1] Geol. Soc. America Bull., vol. 25, p. 47, 1914.

[2] Wells, R. C., and Butler, B. S., Washington Acad. Sci. Jour., vol. 7, pp. 596-599, 1917

will be found elsewhere, though perhaps not in commercial quantities.

Horizon of the bed deposits.—Several horizons in the sedimentary series have apparently been especially favorable to the deposition of ores, though it is a rather striking fact that a given bed does not seem to be uniformly favorable throughout the district. The lowest beds in which important bed deposits have formed is the limestone member of the Cambrian shale. This limestone has been especially productive in the Wasatch mines (Columbus Consolidated) and in the area south of Little Cottonwood Canyon, including the South Hecla, Peruvian, and Albion mines.

The next ore-bearing strata of importance are the dark, "wormy," and mottled limestones immediately above and below the prominent white stratum (division 4, p. 236) in the Cambrian limestone series. So far as observed, no ore bodies have been found in the white limestone, which, however, is useful as a marker.

Ore has been found in these dark beds at the old Reade & Benson mine and at other places on both sides of Reade and Benson Ridge. The deposits of the Carbonate mine are in these strata, as are apparently the lower deposits in Michigan-Utah and Alta Consolidated properties. Some of the deposits in the American Fork district are apparently in these beds.

It is frequently said that the ore bodies of the Flagstaff, Old Emma, and certain other mines are in the same strata as the Reade & Benson deposits, but this statement is an error, due to the confounding of the Cambrian white bed with a somewhat similar but higher bed.

The white Cambrian limestone, which may readily be traced from the Reade & Benson mine, crops out conspicuously on the slope west of the Flagstaff tunnel with an eastward dip, which, if projected, would bring it close to the portal and very little below the strata that carry the Flagstaff ores. Just west of the tunnel, however, there is a fault with downthrow to the east in consequence of which this limestone crops out below the foot of the great dump. Outcrops of another whitish bed are found along the slope above, more nearly in line with the white band west of the mine. It is in or near this higher bed that the ores of the Flagstaff-Emma zone occur. The bed is the pale-gray fine-grained limestone that lies about 150 feet above the post-Cambrian unconformity (division 4, p. 233). Chemically it seems to be nearly pure calcite; physically it is brittle, and near fissures it has broken or cracked into small pieces. It is probable that the combination of favorable chemical composition and physical properties has caused this limestone to be the most productive of the district. In addition to the deposits of the Flagstaff-Emma zone others occur at nearly the same horizon in the Michigan-Utah mine and in the Prince of Wales mine.

Ore deposits occur in higher limestones in the district, but no well-defined productive bed above that of the Flagstaff has been recognized. The stratigraphic series in the underthrust block has not yet been definitely correlated with that of the overthrust. There is apparently a rather definite horizon in this lower block at which ore deposits of the South Hecla and Sells mines have formed. This may prove to be essentially the same as the Flagstaff-Old Emma zone. Other deposits in the lower block cut across the strata and are apparently controlled more by physical conditions than by the composition of the replaced limestone.

Physical condition of replaced rock.—The physical condition of the replaced rock has probably been an important if not a controlling factor in the formation of the deposits that occur in the limestones immediately beneath the thrust-fault planes. This is indicated by the facts that deposits have formed in beds that in their normal condition have apparently not been particularly favorable to ore deposition, and that only where limestone is overridden by a hard rock, as limestone, quartzite, or siliceous shale, and strongly brecciated, have such contacts been shown to be especially favorable. Where weak clay shale has been thrust upon limestone, ore has not yet been found in large bodies. Ore bodies connected with faults that have thrust quartzite and siliceous shale over limestone have been developed in the Cardiff, Columbus-Rexall, Wasatch (Columbus Consolidated), South Hecla, and Cottonwood-Atlantis properties. Extensive areas of such contacts have not yet been thoroughly prospected. Where limestones have been brought together by thrust faulting a brecciation has resulted that has apparently been favorable to ore deposition. Such con-

ditions are present in the Michigan-Utah and possibly in the Old Emma mine.

The deposits of the Flagstaff-Emma zone are all very similar in occurrence. The zone is crossed by a series of northeast fissures, with some fissures striking north and west of north, at whose intersection with the ore-bearing limestone the ore deposits occur in forms varying from chimney-like to roughly tabular, according to the distance from the fissure to which mineralization has extended. Most of the openings in the ore bodies along this belt were inaccessible at the time of visit; the following statements are based on what could then be seen and on old mine maps and reports.

The limestone of the replaced beds near the fissures has been much shattered and in the Old Emma deposit forms a very distinct breccia that probably represents movement parallel with the beds as well as along the fissures. This breaking of the limestone into fragments gave a large surface for solutions to act upon and was doubtless a considerable factor in the production of the ore deposits in this bed of limestone. In some localities the limestone was largely replaced by ore and gangue minerals, in others much of the limestone was not replaced, the ore minerals forming around the fragments.

The deposits mined have been largely oxidized, but the original metallic minerals probably consisted largely of galena, pyrite, tetrahedrite, sphalerite, and some silver mineral or minerals, as argentite or pyrargyrite.

The Old Emma ore body was cut off about 475 feet below the surface by the Montezuma fault, a north-south fault with downthrow to the east. The continuation of the ore east of the fault and 250 feet lower was opened in 1917, and in the summer of that year it had been followed down for about 300 feet. The ore below the fault shows little oxidation. The metallic minerals are pyrite, galena, tetrahedrite, argentite and possibly other silver minerals, tungstenite, and a little sphalerite. The chief gangue minerals are quartz and unreplaced and recrystallized limestone. For at least a part of the shoot there is a central core which consists mainly of quartz that has completely replaced the limestone and contains but relatively small amounts of the metallic minerals. The limestone breccia surrounding this core is less completely replaced and sulphides are more abundant. The ore shoots to the northwest of the Emma shoot on the Emma-Flagstaff belt have been cut by north-south faults and dislocated to distances ranging from a few feet to at least 40 feet and probably considerably more. In nearly all the shoots that have been mined the most of the ore was within a few hundred feet of the surface; at greater depth on the dip of the ore bed the shoots decreased both in size and in content of lead and silver.

The character of the ore bodies mined in the early days can be gathered from the following quotation from Huntley:[1]

> The ore-bearing formation [Old Emma] is a belt of siliceous limestone, between a limestone hanging and a dolomite foot wall, the belt being about 200 feet wide, dipping 45° NE., parallel to the stratification of the country rock. The ore did not come to the surface but was found by following a small seam of ocher 50 feet in a tunnel. Two large bodies were found somewhat nearer to the hanging than to the foot wall, following the general dip and strike of the belt. One began near the surface and was 100 feet deep, 300 feet long, and from 1 to 30 feet wide; and the other, a few feet below the first, was 200 feet long, 150 feet deep, and from 1 to 20 feet wide. The ore was a soft brownish-red ocher, containing cerusite, anglesite, galena, and some manganese oxide.

Emma mine.—In 1872 Raymond[2] described the Emma mine as follows:

> The Emma mine is one of the most remarkable deposits of argentiferous ore ever opened. Without any well-marked outcroppings, there was nothing upon the surface to indicate the presence of such a mass of ore except a slight discoloration of the limestone and a few ferruginous streaks visible in the face of a cut made for starting the shaft. Some of the earliest locators in the canyon assert, however, that in the little ravines below this shaft large masses of galena, some weighing over 100 pounds, were found upon the surface and in the soil. After the discovery of the deposit by means of the shaft a tunnel was run in so as to intersect it in depth. This tunnel extends in a northwesterly direction and is 305 feet long. It intersects the ore mass where it was about 60 feet long and 40 feet wide, measured horizontally. From this level, called the first floor, ore has been mined above and below until an excavation or chamber has been formed varying from 20 to 50 feet in width and from 50 to 70 in length and 77 in height above the tunnel level and 50 in depth below.
>
> In August last a portion of the ore below the tunnel level was still standing, but the mine had produced from 10,000 to 12,000 tons of ore, assaying from 100 to 216 ounces of silver per ton of 2,000 pounds and from 30 to 66 per cent of lead, averaging about 160 ounces of silver and from 45 to 50 per cent of lead. The total value of

[1] Huntley, D. B., op. cit., p. 423.

[2] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1871, p. 321, 1872.

this ore, at the cash price paid for a large part of it in Liverpool, £36, or $175 in round numbers, was about $2,000,000.

This ore was extracted at comparatively little cost. Most of it was stoped from below upward and was delivered by chutes into the cars upon the tramway laid in the tunnel. In general the ore was soft and easily excavated by picks and shovels, without the aid of gunpowder. It consisted chiefly of ferruginous and earthy-looking mixtures of carbonate and oxide of lead, oxide of iron, and of antimony, mixed with nodules of galena. It appears to have resulted from the decomposition of argentiferous galena and other sulphureted and antimonial minerals containing silver. The ore may be said to be without gangue and does not require hand sorting or separating by mechanical means from worthless vein stone. This ore was shoveled up and put into sacks for shipment without any other delay or expense. The larger part was shipped overland by railroad to New York, and thence by steamer to Liverpool.

The walls of the excavation are very irregular but consist of a hard, white, dolomitic limestone. The ore mass appears to conform to the stratification and to have a general northwesterly direction, dipping to the northeast. The extent of the ore mass in the direction of its length had not been fully ascertained at some of the levels when I visited the mine in July, though in most of the floors it had all been taken out, and the form of the excavation may be taken as marking in a general way the limits of the main body. A peculiar brecciated mass of dolomitic limestone accompanies the ore and may be regarded as vein matter, for nodules of galena are found isolated in its midst, as well as small patches of soft earthy ore disconnected with the main body. The limits of this ore-bearing breccia are not yet ascertained, and prospecting drifts to the northwest along its course may reach other bodies of rich ore.

Raymond[1] quotes from a description of the ores by Silliman, as follows:

The ores of the mines thus far opened in the Wasatch Mountains are largely composed of species resulting from the oxidation of sulphides, especially galenite and antimonial galena, with some salts of zinc and copper, all containing silver and rarely a little gold. Iron and manganese ochers occur in considerable quantity in some of them, but the process of oxidation has prevailed very extensively, so that the ochraceous character of the ores is the striking feature of most of the mines in this range.

The great chamber of the Emma mine * * * was found to be filled almost exclusively with epigene species, the product of oxidation of sulphides, and capable of removal without the aid of gunpowder for the most part. The study of this mass reveals the interesting fact that it is very largely composed of metallic oxides, with but comparatively small proportions of carbonates and sulphates. Fortunately I am able to present an analysis of an average sample of 82 tons (183,680 pounds) of first-class ore from Emma mine, made by James P. Merry, of Swansea, April, 1871, which is as follows, viz:

[1] Raymond, R. W., op. cit., p. 325.

Silica	40.90
Lead	34.14
Sulphur	2.37
Antimony	2.27
Copper	.83
Zinc	2.92
Manganese	.15
Iron	3.54
Silver	.48
Alumina	.35
Magnesia	.25
Lime	.72
Carbonic acid	1.50
	90.42
Oxygen and water by difference	9.58
	100.00

The quantity of silver obtained from this lot of ore was 156 troy ounces to the gross ton of 2,240 pounds.

This analysis sheds important light on the chemical history of this remarkable metallic deposit and will aid us in the study of the paragenesis of the derived species. It is pretty certain that all the heavy metals have existed originally as sulphides, and we may, therefore, state the analysis thus, allowing 8.52 sulphur to convert the heavy metals to this state:

Silica	40.90
Metallic sulphides	52.60
Al, .35; Mg, .25; Ca, 72; $\dddot{Mn}_2$; $\dddot{Mn}$, .20	1.52
	95.20
Water, carbonic acid, and loss	4.95

This calculation assumes that the sulphides are as follows, viz:

Galenite	38.69
Stibnite	3.30
Bornite	1.03
Sphalerite (blende)	3.62
Pyrite	5.42
Argentite	.54
	52.60

This statement excludes the presence of any other gangue than silica, and considering that the ores exist in limestone, the almost total absence of lime in the composition of the average mass is certainly remarkable. The amount of silica found is noticeable, since quartz is not seen as such in this great ore chamber, nor, so far as I could find, in other parts of the mine. The silica can have existed in chemical combination only in the most inconsiderable quantity, since the bases with which it could have combined are present to the extent of less than 1½ per cent; nor do we find in the mine any noticeable quantity of kaolin or lithomarge, resulting from the decomposition of silicates, nor are there any feldspathic minerals. It is most probable that the silica existed in a state of minute subdivision diffused in the sulphides, as I have seen it in some of the unchanged silver ores of Lion Hill, in the Oquirrh Range.

The absence of chlorine and of phosphoric acid in the analysis corresponds well with absence of the species

cerargyrite and pyromorphite, of which no trace could be found by the most careful search among the contents of the mine. The miners speak of the "chlorides," and the unscientific observers have repeated the statement that silver chloride is found in the Emma mine, but the ores indicated to me as such are chiefly antimonic ochers.

The general (perhaps total) absence of the phosphates of lead in the Wasatch and Oquirrh mountains, so far as explored, is a striking peculiarity of the mineralogy of these ranges. On the other hand, the absence of chlorine in the mines of the two Cottonwoods and the American Fork is in striking contrast with the constant occurrence of cerargyrite (horn silver) in the Oquirrh and also in the southern extension of the Wasatch. I have sought in vain for a trace of this species in the districts of the Wasatch just named, and the occurrence of pyromorphite is extremely doubtful.

Molybdic acid, however, exists pretty uniformly disseminated in the mines of the Wasatch in the form of wulfenite. Although it occurs in minute quantity, it is rarely absent, and may be regarded as a mineralogical characteristic of the districts of the two Cottonwoods and of the American Fork. For this reason a few particulars will be in place here.

Wulfenite is found associated with calamine (smithsonite), cerusite, malachite, azurite, and more rarely alone in little cavities in the ochraceous ores. In the Emma mine vugs or geodes are occasionally found lined with botryoidal apple-green calamine, rarely crystallized, often brownish and sometimes colorless, but invariably associated with wulfenite. The calamine incloses and covers the crystals of wulfenite, which form a lining of considerable thickness. The wulfenite is in thin tabular crystals of a yellow color, resembling the Carinthian variety of this species. The crystals are very brilliant and perfect but quite minute, rarely 2 or 3 millimeters in width and not over 1 millimeter in thickness, often less. They are quite abundant in this association, no piece of the calamine which I have seen being without them. They sometimes, but rarely, penetrate through the globules of the calamine so as to show themselves on the upper surface of that species. But the calamine has obviously formed botryoidal masses around the wulfenite, a crystal of this species being often seen forming the nucleus of the calamine globules.

These facts are of interest in the paragenesis of these epigene species. The order of production has obviously been, first, the cerusite resting on ochraceous iron, manganese, and other metallic oxides; next, the wulfenite crystals were deposited upon and among the crystals of cerusite; and lastly came the calamine, crystalline at first and as it accumulated becoming fibrous and amorphous, completely inclosing and capping the other species.

Wulfenite occurs also in this mine, as likewise in the Flagstaff, the Savage, and Robert Emmet, without the calamine, but never, as far as observed, without cerusite and other carbonates. In the Savage masses of cerusite, with various oxides, are interpenetrated by the tabular crystals of wulfenite.

Although wulfenite forms a very minute factor of the entire ore mass in these mines, by the law of mineral association it may be considered as the characteristic species of the ores of these districts, occurring in the magnesian limestones. * * *

The oxidizing and desulphurizing agency which has acted upon the great ore mass of the Emma mine, whatever it was, has performed its work with remarkable thoroughness. A careful study of its action discloses some other facts of interest in the paragenesis of species. From the appearance of numerous large blocks of ore, forming solid boulders in the general mass, a concentric arrangement is easily recognized. On breaking these masses across, the fresh fractures disclose a dark center which consists almost entirely of decomposed sulphides, composed chiefly of cerusite blackened by argentite and metallic silver in a pulverulent form. This dark center, chiefly of cerusite, is often pseudomorphic of galenite in its fracture. Next is usually a zone of yellowish and orange-yellow antimonial ocher, cervantite, often quite pulverulent, at times only staining the cerusite; then follows a narrow zone of green and blue copper salts, malachite, azurite, cupreous anglesite, with, rarely, wulfenite; then follows cerusite, sometimes stained with antimony ocher, and not unfrequently associated with wulfenite; outside all are the iron and manganese ochers. This concentric arrangement I have observed in a great number of cases; and the above order of species, while not invariable, is believed to reflect accurately the general arrangement. Well-crystallized species, as mineralogical specimens, are rare in this great mass; but the following may be recognized as its chief components: *Galenite*, sphalerite, pyrite, jamesonite (?), argentite, stephanite, boulangerite (?), *antimonial galenite*, *cervantite*, mimetite (?), limonite, wad, kaolin, lithomarge, *cerusite*, anglesite, linarite, *wulfenite*, *azurite*, *malachite*, *smithsonite*. Those most abundant or best crystallized are in italic. This list can no doubt be extended as opportunity occurs for the more careful study of the ores, the great mass of which, amounting to many thousand tons, have gone into commerce without passing under any mineralogical eye.

Flagstaff mine.—The Flagstaff mine was located and worked about the same time as the Emma and like the Emma was long idle. Huntley[1] gives the following description of the deposit:

The formation is the same mineral belt as the Emma. Ore came to the surface in one spot, and following this indication a short distance the discoverers came to the first and largest body. It was 400 feet long and 500 feet deep, extreme dimensions, and 3 feet wide. Some 20 or 30 other large-sized bodies were found, in all shapes and positions, usually near the hanging wall and invariably connected with one another by a small seam of ore of ocher. One body upon the footwall was joined to another near the hanging wall by a pipe of galena the size of a lead pencil.

Vallejo and North Star claims.—Huntley[2] gives the following description of the ore bodies of the Vallejo and North Star claims:

The ore is found in irregular shoots or pipes near the hanging wall. Three bodies began near the grass roots, and others were found as depth was attained. At the period under review there were 10 shoots having a tri-

[1] Huntly, D. B., op. cit., p. 423.
[2] Idem, p. 424.

angular or lenticular cross section and a uniform dip SE. 80°. These were from 20 to 100 feet apart and lay almost at right angles to the strike of the belt. The largest was 150 feet long, extreme dimensions from 6 inches to 10 feet wide, and has been followed 300 feet deep.

Cabin mine.—The Cabin mine is just northeast of Alta. The limestone in which the ores occur appears to be lower than that of the Flagstaff, though there is yet some doubt, owing to the incomplete understanding of the complex faulting. The deposits occur in a bed of white limestone associated with a strong fissure, the ore forming irregular "chimneys" along fractures in the limestone. The ore consists of galena, pyrite, cerusite, anglesite, some copper carbonate, and a yellow earthy sulphate of lead and iron, probably plumbojarosite, that is said to contain considerable silver.

South Hecla mine.—Some of the largest deposits in the South Hecla mine may be classed as bed deposits, in that in general they follow the intersections of fissures and certain beds of limestone. A characteristic feature of these deposits is the highly brecciated condition of the mineralized limestone adjacent to the fissure, which has been partly replaced by the ore minerals. Most of the ore is screened to separate the unreplaced portion of limestone from the metallic minerals.

The No. 1 shoot on the Wedge fissure above and below the Dwyer tunnel is of this type, as is the ore shoot on the Kate Hayes fissure, worked from the fourth east crosscut of the Quincy tunnel. The No. 2 shoot on the Wedge fissure, on the other hand, crosses the bedding planes of the limestone, and the brecciation appears to have resulted from the intersection of the fissure and an earlier break in the limestone. A porphyry dike follows the shoot rather closely, and the intrusion of this dike may have had an important influence on the character of the limestone.

Other mines.—Deposits similar to those in the South Hecla, in that the ore shoots have formed in the brecciated portions of certain limestone beds adjacent to fissures, are present in the Sells, Peruvian, and Albion mines. Some of the largest deposits of the Alta Consolidated mine extend into certain beds from fissures and may be regarded as bed deposits, though at some places the deposits are rather closely confined to the fissures.

BIG COTTONWOOD DISTRICT.

The Prince of Wales and other mines are just north of the Cottonwood Divide on Silver Fork, a branch of Cottonwood Creek. Like many of the other mines of the district they were worked extensively in the early days and were then idle for a long period. In the last few years considerable work has been done and some ore shipped by lessees. The structure of the Prince of Wales hill is very complex and has not been completely worked out. There are at least two overthrust faults which bring Cambrian limestone over Carboniferous limestone. The limestone in which the main ore shoots occur are probably at the same horizon as those of the Flagstaff-Emma zone and some of those of the Michigan-Utah mine.

Prince of Wales mine.—Huntley [1] gives the following description of the Prince of Wales deposits:

The ore-bearing formation is said to be a bedded vein, dipping about 45° NW. in blue and white limestone. Four distinct chimneys or shoots of ore, 130 feet, 200 feet, and 260 feet apart, have been found. They occur where the limestone is white, metamorphic, and soft, while the barren spaces between these shoots contain the vein only as a narrow seam in hard blue limestone. These shoots outcropped at the surface, or were covered by a few feet of drift, as low-grade, ocher-stained seams of limestone and clay. Good ore was found by sinking a few feet. The Antelope and Prince of Wales shoot is from 2 inches to 4 feet (average, 12 inches) wide, 120 feet long, and has been followed on the dip 1,200 feet. The Highland Chief shoot is from 2 inches to 3 feet (average, 8 inches) wide, 75 feet long, and 800 feet deep. The Wellington shoots are each about from 2½ to 7 feet (average, 3 feet) wide, from 10 to 30 feet long, and 700 feet deep. The ore from the first assays about 140 ounces silver and 45 per cent lead; that from the second, 100 ounces silver and 40 per cent lead; and that from the third and fourth, 60 ounces silver and 50 per cent lead. The ore is a soft brownish-yellow ocher, containing argentiferous cerusite and galena and occasional stains of oxides of manganese and copper.

In 1916 and 1917 work was being carried on from the lowest tunnel level on the Honeycomb Fork side and drifting on the vein below the old tunnel level was in progress. The ore, which ranges in thickness from that of a knife blade to a little more than 6 inches, consists mainly of galena surrounded by oxidation products. The ore bodies, so far as developed on the lowest level, seem to be smaller than those at higher levels, but the content of silver

[1] Huntley, D. B., op. cit., p. 428.

and lead seems to be quite as high as in the upper workings.

Kennebec group.—The old Reade & Benson mine, which was an important producer in the early days, is now a part of the Kennebec group. Two tunnels have been driven on the Kennebec property to explore the ground at greater depth than the old workings of the Reade & Benson but as yet have developed no ore. The ore bodies have formed in a spotted and mottled Cambrian limestone lying below and above the band of thinly laminated white limestone (division 4, p. 236). The beds are below those in which the Flagstaff deposits occur. Huntley has described the early workings as follows:

The Reade & Benson mine is situated on a spur of the Cottonwood Divide, between Day's and South forks, 11,000 feet above sea level and 2½ miles northwest of Alta. It was located in 1870 and was worked vigorously from September, 1871, until April, 1878. Since then it has been idle or leased to a very limited extent. This mine is supposed to be upon the same mineral belt as the Flagstaff and the Emma. The belt at this point is about 200 feet wide. The ore occurs in a vein or chimney on the hanging-wall side and in about 20 irregular lenticular bodies, which branch at all angles from the chimney, on its footwall side. These do not, as a rule, extend more than 75 feet from the main chimney and vary from 6 inches to several feet in width. One outcropped as a low-grade ocher. The largest is about 170 feet from the surface. The ore is of the kind usually found in this limestone formation, namely, a yellow and red oxide of iron carrying argentiferous cerusite and galena. It is claimed that the total shipments have averaged 120 ounces silver and 35 per cent lead per ton. The mine is developed by a 380-foot tunnel, in which there is a whim on a 400-foot incline, dipping 35° NNE. Below this there are four windlasses, which carry the incline down 400 or 500 feet deeper. In general, the mine may be said to have been opened from the surface 1,100 feet on the dip (35°) by an irregular incline following the chimney. Near the surface the ore extended 100 feet and the workings 200 feet horizontally; but in the bottom of the incline not over 40 feet of drifting have been done. The openings have a total length of 1,950 feet.

The Ophir is a few hundred feet southwest of the Reade & Benson. * * * It was discovered in 1870, purchased by Reade & Goodspeed in 1871, leased until May, 1878, and worked steadily since by about 10 men. Ore is found in three bodies in a 30-foot stratum of compact dark-blue limestone. A stratum of white limestone above carried no ore. The outcrop was a pipe 2½ feet in diameter of low-grade ocher. The shape of the bodies is that of a flattened or an elongated ball, the largest being 50 by 20 by 15 feet. They are 4 and 10 feet apart and not over 50 feet from the surface. At the period under review drifting was being carried on upon a seam of ocher in the expectation of finding another body. The total cuttings did not exceed 700 feet. During the census year 173 tons of ore similar to that of the Reade & Benson, excepting that it was of lower grade, assaying only about 45 per cent lead, 42 ounces silver, with 3 per cent moisture, were sold for $8,581. The previous product was estimated at $22,000.

Carbonate mine.—The Carbonate mine,[1] in common with many others of the region, made an important production in the early days and then little for a long period. In the last few years lessees have extracted considerable oxidized zinc ore and some lead-silver ore.

The ore bodies are in the spotted and mottled Cambrian limestones near the base of the great limestone series, apparently at the same horizon as the old Reade & Benson deposits. Just south of the mine a strong east-west fault has thrown the limestone down against the Cambrian quartzite. The limestone is cut by fissures striking about N. 75° W. and dipping steeply south. Fissures that strike in other directions seem to be less important with relation to the ore bodies, though one, striking about N. 40° E. and dipping northwest (corresponding in general to the direction of most of the ore fissures of the district), may be more important than is apparent. The rocks have been broken since the primary mineralization by nearly vertical north-south joints, which have influenced the deposition of the secondary deposits, notably the oxidized zinc ores.

The ore deposits have replaced certain beds of limestone adjacent to the fissures. Two factors appear to have controlled the replacement, the composition of the limestones and the degree to which they are fractured. The deposits are largely oxidized, but the original minerals were probably sulphides of lead, iron, zinc, and copper, together with some manganiferous mineral. In the oxidation the lead remained essentially in its original position, but the zinc, iron, manganese, and copper were largely leached into the adjacent limestone, where they were in part precipitated. The oxidized zinc deposits occur mainly beneath and for some distance up along the sides of the old lead stopes and along the north-south joints. Iron and manganese are rather abundant in the oxidized zinc ores. It is said that some of the lead ores consisted largely of galena, and it seems certain that galena must have persisted after the other sulphides had been largely oxidized. Copper was not an important constituent of the ore, though small

[1] The writers are indebted to Mr. G. H. Ryan for much information relating to the Carbonate mine.

bodies of good copper ore have been found. Beautiful specimens of the copper-zinc carbonate, aurichalcite, occur in the mine. The following description of the early operations of the mine is given by Huntley:[1]

The mine of the Kessler Mining Co. covers part of the ground of the old Provo claim. It was worked by a New York company in 1872, 1873, and 1874. Little ore was obtained, and it was abandoned. About 1875 a prospector discovered the carbonate ore body while overhauling the old dump, so says tradition. The mine was bought by the Carbonate Co., of Salt Lake City, which extracted large quantities of ore. In January, 1879, after the large discovery the mine was sold to the Kessler Mining Co., of New York City. This company took out considerable ore and did much prospecting but ceased work some months previous to the writer's visit, at which time the mine was worked by a few lessees. The property consists of the following overlapping unpatented claims: Carbonate (1,500 by 200 feet), Little Giant, Sailor Jack, Alturas, Baker, and Defiance. These are situated on the summit of the ridge of Silver Mountain, about 11,000 feet above sea level, 3 miles south of Argenta, and about 7 miles northwest of Alta. * * * The ore is found in several bodies near the surface on the hanging-wall side of a stratum or belt of limestone. The largest body was just below the surface and was lenticular in shape, its dimensions being 200 by 100 by 50 feet. It was timbered by 365 square sets but had caved in. The gangue, if such it may be called, which surrounds the bodies and also serves as a connecting link between them, consists of a valueless ocher or limonite. It is very abundant, sometimes fine and soft; at other points hard and siliceous. Occasionally heavy spar, oxide of manganese, and stains of malachite are found. The ore is an ocher, containing cerusite and galena, and assays from 30 to 50 per cent lead and from 30 to 100 ounces silver. A fissure vein, called the "Sailor Jack," connects with this body and has been the cause of much litigation. There is also a vertical fault of 500 feet. * * * The total product of the mine prior to October, 1877, is estimated at $120,000. Between the above date and the beginning of [1880] the census year 4,549 gross tons, averaging about 8 per cent moisture, were sold for $261,044.41.

Maxfield mine.—The Maxfield mine is about 7 miles from the mouth of Big Cottonwood Canyon. The ore body crops out in Maxfield Gulch, a few hundred feet north of its junction with the main canyon. The sedimentary rocks are the Cambrian quartzite, the Cambrian shale and limestone, and the great series of post-Cambrian limestones. All these rocks are cut by dikes of monzonitic porphyry. The largest dike, which crops out in Maxfield Gulch northeast of the mine workings, is several hundred feet wide and can be followed along the west fork of the gulch to an elevation of 400 or 500 feet above the canyon. Dikes cut the limestone in the Baker mine, are exposed in road cuts along Big Cottonwood Canyon, and are cut at numerous points in the northeastern extension of the Maxwell workings, both on the main tunnel level and at higher levels. Small dikes and sills of the porphyry extend along fissures and along certain of the beds.

The limestone adjacent to the dikes has commonly been altered to a mixture of silicates and calcite. Epidote and mica are the most abundant, but garnet and probably other silicates are present. Magnetite, hematite, and sulphides are nearly or quite lacking. In many places the porphyry appears to have undergone an alteration similar to that of the limestone, indicating that it had solidified before the time of the alteration.

Numerous fissures in the limestone strike from a few degrees west of north to N. 20° E. and dip irregularly. The Alligator fissure, which is believed though not proved to be the same as the Logger fissure, on the opposite side of Big Cottonwood Canyon, is perhaps the most regular, with steep westerly dip, but even this varies considerably at depth.

The larger ore deposits of the mine have formed in a bed of banded blue and white limestone near the base of the great limestone series. The ore has replaced the limestone adjacent to fissures, forming chimneys of varying size. The deposits so far developed appear to form a northwestward-pitching zone near the porphyry dikes. This belt has been followed from the outcrop in Maxfield Gulch to the bottom of the Alligator extension winze, a distance of more than 1,300 feet. In the older workings several of the pipes of ore have been followed to the porphyry dikes. Near the dikes the lead and silver content becomes unprofitable, although the limonite persists. The limestone adjacent to fissures near the dikes is partly replaced by silicates, including mica and epidote.

The ore is rarely if ever found where the limestone has been replaced by the silicates—a fact which suggests that the ore solutions came up along the dikes and passed into the fissures. The absence of ore and the presence of silicates near the dikes may be interpreted as indicating that the conditions of temperature, pressure, etc., near the dikes were not favorable to the deposition of the ore minerals.

[1] Op. cit., p. 436.

Operations are conducted through a tunnel from Big Cottonwood Canyon that intersects the ore zone about 1,000 feet from the portal. The ore zone has been followed for a distance of more than 1,000 feet northwest, and, in the Alligator extension winze and main shaft, to a depth of about 140 feet vertically below the tunnel. In the summer of 1916 ore was being extracted at this depth from the Alligator shoot and prospecting was being carried on from the tunnel level. Much of the ore above the tunnel level was oxidized, but below the tunnel the ore is mainly sulphides, pyrite, galena, and tetrahedrite. The large amount of water has handicapped prospecting and development. Huntley [1] gives the following description of the old workings:

The Maxfield is a bedded vein, from 1 to 8 feet wide, dipping 45° NE. between strata of a compact bluish-white limestone. The ore occurs usually upon the footwall, in one chimney 200 feet long and 2 feet wide. It is a soft brown ochery carbonate and galena, assaying from 30 to 100 ounces. On the hanging wall there was a band of quartz, from 3 to 8 inches wide, containing galena and pyrites. When carefully sorted this yields good ore.

AMERICAN FORK DISTRICT.[2]

The only bed deposits in the American Fork district are those of the famous old Miller mine, on Miller Hill, just east of the divide between the head of American Fork canyon and Mary Ellen Gulch. According to Huntley [3] the mine "was discovered in 1870 and was sold the following year for $120,000 or over." It was examined in 1872 by J. P. Kimball, from whose published report the following data are abstracted:

The earliest workings were inaccessible in 1872. The "vein" then worked lies near the base of the limestone series and follows the bedding, which dips 15°–25° SE. The ore cropped out on the southwest side of the hill and was followed along the footwall for about 120 feet, when it "rolled" downward for a short distance and again followed the bedding. Below the roll (at the car tunnel) the "vein" was 17 feet thick. The footwall was clearly defined, but the top of the ore body graded into the limestone. The footwall was a bed of "tight lime," with a streak of clay selvage marking the contact with the ore The hanging wall was shaly, much fractured, and partly altered to "ocherous matter." Fragments of the hanging-wall rock were found throughout the vein. The east side of the old incline showed either a steep pitch, a horse of loosened rock, or a fault causing the abrupt disappearance of the vein material on this side. Not enough work had been done at the time to determine the structure.

Quartz and calcite were generally absent, except as "a residue of country rock." The ore minerals were galena, cerusite, and "plumbic ocher," all carrying silver. Considerable hydrous ferric oxide was present, presumably an alteration product or pyrite, and the green and blue stains of copper carbonate were found in drusy cavities in the hanging wall. Black manganese stains were commonly present with the iron oxide.

Cerusite, both black and white, was the most abundant of the three lead minerals. The black variety probably owed its color, in Kimball's opinion, to finely divided silver sulphide, and was the rich ore of the mine, "containing 83 per cent lead, along with some 76 ounces of silver to the ton." This black variety must have been largely galena, for pure cerusite contains only 76 per cent of lead, whereas galena contains 86 per cent. It occurred in granular masses in the lower and middle parts of the "vein." Some of the masses were 1 to 6 feet in diameter and constituted from 10 to 16 per cent of the total ore shipped. The white variety, carrying about 60 ounces of silver to the ton, was the predominant ore and in a concentrated form occupied the lower half of the ore body. It was arranged in lenticular layers, separated by thin seams of clay and "plumbic ocher." "Perfectly pure lenses" of it, 3 to 5 feet thick, had the consistency of quicksand. The "plumbic ocher" occurred in irregularly distributed masses or lenses in the lower part of the vein and carried as much as 36 ounces of silver and 2.45 ounces of gold to the ton. Some gold was also present in the ferric oxide. The upper part of the "vein" consisted of brecciated limestone and ferric oxide, the former more or less impregnated with copper salts and partly oxidized galena. The ore body was said to be the largest deposit of lead carbonate known.

[1] Huntley, D. B., op cit., pp. 427–430.

[2] The descriptions of the deposits in the American Fork district are by G. F. Loughlin.

[3] Huntley, D. B., op. cit., pp. 444–445.

The following table of assays, taken from Kimball's report, represents the western ore bodies of the mine, worked up to 1872:

Assays of ore from Miller mine.

Kind of ore.	Lead.	Silver.	Gold.
	Per cent.	*Ounces to the ton.*	*Ounces to the ton.*
Galena	56	25.51	0.30
Do	70	38.88	.60
Do	64	125.97	None.
Do	62	45.20	.43
Gray [white?] carbonate and galena	75	84.62	.75
Gray [white?] carbonate	60	30.37	.60
Black carbonate	68	38.45	Trace.
Do	72	36.57	Trace.
Carbonate	75	35.07	2.34
Do	83	31.49	2.77
Oxide of lead	([a])	25.8	([b])
Third-class vein matter	40	16.96	None.
Run of mine	58	29.16	.50
Do	53	27.32	.60
Do	60	30.37	.60
Do	57	33.41	.60
Do	55	36.00	([a])

[a] Not determined. [b] Included in silver.

The average value per ton of base bullion produced from these ores at the old Sultan smelter in American Fork Canyon for 60 working days was as follows: Lead, \$140.70; silver (60.36 ounces), \$86.47; gold (0.97 ounce), \$22.27; total, \$249.44.

According to Huntley,[1] ore was found in six or eight large bodies which began within 70 feet of the surface in a belt of dolomite. About 4,800 tons was extracted from the largest body. In addition to the minerals mentioned by Kimball, wulfenite was present in the oxidized ore, and a little zinc blende and pyrite were found below water level (500 feet). The total production of the old workings was estimated to have been between 13,000 and 15,000 tons, assaying 40 to 54 per cent of lead and 30 to 47 ounces of silver and \$2 to \$10 in gold to the ton. These figures do not range as high as some of those given by Kimball.

The old ore bodies gave out and the company ceased operations in December, 1876, and since that time the mine has been worked by lessees. No great amount of ore was produced until 1905, when the Tyng Bros., then leasing, opened another large body, which replaced the limestone along a nearly due east fissure for a total distance of over 400 feet and was 10 to 40 feet wide. The increased production from 1905 to 1908 was due to this deposit. The rock replaced was a gray dolomite (?), overlain and underlain by shaly limestone. Two other bodies, smaller and less regular, were found 100 feet north of the main body, one on each side of a porphyry dike, whose strike is about N. 70° E. The main ore body ended abruptly on the east, possibly against a fault, and a search has recently been made for its eastward continuation, but up to 1913 only relatively low-grade oxidized ore had been found. The ore was principally rusted "sand carbonate" containing residual boulders of galena and showing copper stains but assaying less than 2 per cent copper. The average content of the ore shipped from the Tyng lease was 0.98 ounce of gold and 21.72 ounces of silver to the ton, 39.29 per cent of lead, 4.90 per cent of zinc, 20.17 per cent of iron, 2.61 per cent of sulphur, and 3.56 per cent of insoluble matter. These figures show that the ore was mostly oxidized and contained very little quartz or barite gangue.

Shipments of low-grade ore along the fault(?) east of the main body, in 1913, averaged about \$6 in gold and 11 ounces of silver to the ton, 18 per cent of lead, 37 per cent of iron, 2.5 per cent of zinc, 2.3 per cent of sulphur, and 2.7 per cent of insoluble matter.

DEPOSITS ASSOCIATED WITH THRUST FAULTS.

General features.—Several deposits associated with thrust faults occur in the two Cottonwood districts. Among the more important of this type thus far developed are those of the Cardiff mine, the Wasatch mines (old Columbus Consolidated), and the Columbus-Rexall mine. Similar deposits occur in the South Hecla and Cottonwood-Atlantis. Some of the deposits of the Michigan-Utah mine are also probably associated with thrust faults.

The rocks adjacent to the thrust zones have been rather highly brecciated, especially where a hard rock like quartzite or siliceous shale has been thrust upon limestone. This brecciation of the limestone has proved favorable to mineralization. Where the softer clay shales have been thrust upon limestone particularly favorable conditions do not seem to have resulted. The ore deposits were formed where these zones are crossed by the mineralizing

[1] Huntley, D. B., op. cit., pp. 444-445.

A. VIEW IN MILL D (SOUTH) FORK, BIG COTTONWOOD CANYON, SHOWING CARDIFF AND OTHER MINES.

1, Cardiff mine, lower tunnel; 2, Rexall mine.

B. VIEW ON NORTH SIDE OF LITTLE COTTONWOOD CANYON NEAR ALTA.

1, Tom Moore tunnel; 2, Big City tunnel; 3, Michigan-Utah mine.

fissures, and like the bed deposits, the ore shoots dip with the intersection of the fissures and the fault zones, commonly to the northeast.

Valuable ore deposits have been developed on the Alta overthrust, on the Columbus overthrust, and in the Grizzly thrust zone. Those on the Alta overthrust include the deposits of the Cardiff mine, the Columbus-Rexall mine, and the Howland shoot of the Columbus Consolidated (Wasatch) mine. As indicated in the description of this fault (p. 245), it consists in this portion of two branches. On the Howland tunnel the wedge of shale begins just north of the Howland ore body of the Columbus Consolidated mine and apparently extends beyond the Cardiff ore body, though it has not been proved all the way.

Cardiff mine.—The country rock adjacent to the Cardiff mine consists of the "lower limestone," the overthrust quartzite, and the Cambrian shale. The two north-south Superior faults in South Fork (see Pl. XXVII) have thrown the strata up to the west or down to the east. East of these two faults (part of the "east contact") the overthrust quartzite forms the surface; between the faults erosion has removed the quartzite from the surface, leaving the underthrust limestone exposed; beyond the west fault the limestone and the underlying shale has in turn been stripped away from the lower band of quartzite.

The large ore body of the Cardiff mine occurs on the thrust contact in the block east of the east Superior fault. The overthrust quartzite forms the hanging wall, and the underthrust limestone the footwall. The contact dips eastward at a low angle. The ore bodies are closely associated with a strong northeast fissure, from which they make out into the brecciated limestone along the contact. Vein deposits, described on page 268, have formed in this fissure both above and below the fault zone.

The main ore body on the thrust contact was first entered several hundred feet from the east fault. In following the fissure westward before the fault was encountered the crosscut entered a shaly formation that has not been positively identified, but that is possibly the Cambrian shale, which would indicate that the Cardiff ore body that has been developed is on the upper branch of the Alta thrust fault and that at this point the wedge between the two branches contained some limestone overlying the Cambrian shale. The shale formation was also encountered when the ore body was followed up the dip. The fault in that direction therefore appears to truncate the limestone beds till it brings the shale into contact with the overlying quartzite. The amount of mineralization varies considerably at different points along the dip of the ore body, apparently because some beds of limestone have been more favorable to mineralization than others. In the shaly beds, so far as observed, mineralization has been comparatively slight.

The ore thus far extracted is largely oxidized. Below the present tunnel level, however, it consists more and more of sulphides, and at 200 feet below it becomes mainly galena, pyrite, sphalerite, and tetrahedrite. Shipments for 1915 are reported by the company to average 38.2 per cent of lead, 13.4 ounces of silver per ton, and 3 per cent of copper. Second-class ore is stored for future treatment. In 1916 the mine was producing about 100 tons of ore daily. A view showing the lower tunnel is given in Plate XXVIII, *A*.

Columbus-Rexall mine.—The Columbus-Rexall mine is a consolidation of the old Columbus Extension and the Rexall. The claims of the former were mainly in Little Cottonwood Canyon; those of the latter were mainly on the Big Cottonwood side of the divide.

The rocks of the area consist of the pre-Cambrian quartzite and tillite, the Cambrian quartzite, the Cambrian shales and limestone, and the post-Cambrian limestone. The Alta thrust-fault zone passes through the Columbus-Rexall. The lower branch brings the middle and upper members of the Cambrian shale into contact with underlying Carboniferous limestone. The upper branch brings the overthrust quartzite into contact for part of the distance, as exposed in the tunnel, with the post-Cambrian limestone, for part of the distance with the Cambrian shale, and for short distances with limestone that is probably the Cambrian, just above the Cambrian shale. The wedge between the branches of the thrust is cut by minor thrusts and is highly complex in structure.

The ore deposits in the old Columbus Extension portion of the property were on

the upper thrust contact, where it is crossed by northeast fissures and where limestone forms the footwall of the fault. As in other deposits of this type, the ore minerals have replaced the limestone.

The lower thrust has been little prospected, though a crosscut was driven from the upper to the lower contact. The deposits in the Rexall portion of the property are mainly on the contact where the lens of shale has pinched out and the quartzite lies directly on the Carboniferous limestone. The ore deposit discovered in the summer of 1917 had been but slightly developed when examined by the writer. It apparently occurs as a replacement of brecciated limestone along the thrust contact, which is rather flat. From analogy with other deposits of the district it is probable that the Rexall ore body is associated with a northeast fissure, though no such fissure was apparent in the workings at the time of visit.

The ore minerals were mainly pyrite, tetrahedrite, enargite, galena, and a little chalcopyrite. There is little gangue with the metallic minerals. The relative amount of the different minerals varies greatly. In places pyrite is present nearly to the exclusion of the other minerals, while some of the richest ore is largely tetrahedrite. Pyrite was the earliest mineral to form, and the other minerals have formed by replacement of the pyrite. Next to pyrite, tetrahedrite is most abundant. Enargite is plentiful in certain specimens but does not form an important part of the whole, so far as observed. Galena is present in small amount, but the ore contains but a relatively small percentage of lead. Chalcopyrite, so far as observed, is confined to veinlets in the pyrite grains. The sulphide along the minute fissures in the pyrite appears to have been replaced by chalcopyrite instead of by the more abundant tetrahedrite.

The ores mined during the later part of 1917 are reported to have averaged about 9 per cent of copper, 10 ounces of silver per ton, and a little lead and gold.

Wasatch mines.—The country rock of the deposits of the old Columbus Consolidated mine consists of Cambrian quartzite, Cambrian shales, and limestone. Both the Alta and the Columbus thrust faults pass through the area. The Alta fault, where it is exposed in the underground workings of this mine, has thrust the Cambrian quartzite upon the lower portion of the great limestone series, though, as stated above, it is known that to the northwest there are lenses of the Cambrian shale and limestone faulted between the limestone and overlying quartzite. The Columbus fault has thrust the Cambrian quartzite upon the Cambrian limestone and shale. At the surface only small areas of the limestone are exposed along this fault, but underground much larger bodies indicate that the fault truncates the beds. Other minor thrusts are present.

The rocks are cut by several northeast fissures, the strongest of which is apparently the Braine, at whose intersections with the thrust faults large ore bodies occur. These ore shoots have been followed below the tunnel level till the amount of water developed made the working costs prohibitive. In 1917 a drain tunnel was being driven from a point down the canyon to permit the deeper exploration of the ore shoots. The ore minerals were mainly pyrite, galena, and tetrahedrite. As in the Rexall, copper was more abundant than in most of the mines of the district.

Other mines.—In the South Hecla mine both the Alta and higher thrust faults are present. No large deposit has been developed on the Alta thrust, but on the higher thrusts deposits have been developed in the Ophir limestone from which considerable ore has been taken.

In the Cottonwood-Atlantis mine some work has been done on the Alta thrust contact. Ore is said to have been shipped from this deposit in the early days and has also been mined from the Defiance fissure, in the quartzite above the contact. Prospecting was in progress in 1917.

Ore deposits are known to occur in the Grizzly thrust zone, but the writer has not now sufficient data to determine to what extent the deposits of that section are connected with thrust faults. It is probable that further study and further development will show other deposits associated with thrust faults. There are large areas along the thrusts that have not been prospected.

GENESIS OF THE ORES.[1]

The main types of deposits—contact, fissure, and bed—show complete mineralogic gradation and are without doubt of common origin. At several places contact deposits pass into fissure deposits, and, as a rule, the classification into fissure and bed deposits is based on form rather than on any inherent difference in the character of the mineralization.

The deposits in the igneous rocks, so far as shown by present developments, are of little importance in this region, and their relation to the deposits in the adjacent sedimentary rocks is not as clearly shown as in some other districts of the State. The mineralization in the igneous rocks, however, is such as might have been effected by the same solutions that produced the deposits in the sedimentary rocks.

That the source of the metal-bearing solutions is the igneous material that forms the stocks in the region is indicated by the location and character of the deposits. The principal mineralized areas (see Pl. XXVII) of both the Cottonwood-American Fork and the Park City regions are grouped around the Alta-Clayton Peak stock, and are associated with fissures that were apparently formed at the time of its intrusion. This grouping in itself suggests that the ore-bearing solutions were derived from the intrusive material. Moreover, the aplitic and pegmatitic dikes or veins, which were evidently late phases of the igneous activity, contain sulphides in notable amount, suggesting that the solutions which escaped from the igneous bodies carried ore-forming materials. The association of diopside and pyrite both in aplitic veins and in contact deposits is especially suggestive. The deposits, notably the contact deposits, are similar in character to those of other districts where deposition of ores by solutions emanating from igneous sources is pretty definitely established. Of particular significance in this connection are magnetite and the boron mineral ludwigite, for the boron and iron were clearly transferred from the magma to the contact zone.

The deposits in this region are similar in many respects to those of the Park City district, which Boutwell[2] concludes are genetically related to the intrusive rocks. They differ from these, however, in ways that should not be overlooked. The ore deposits of the Park City district are all in the Weber quartzite and higher formations; the known deposits of the Cottonwood area are, with few exceptions, in formations below the Weber quartzite. Few if any deposits of commercial importance are closely associated with the Little Cottonwood stock of granodiorite, intruded into the pre-Cambrian and early Cambrian rocks, most of the important deposits of the region being associated with the Alta-Clayton Peak stock of quartz diorite, intruded into Paleozoic and Mesozoic rocks. Moreover, there is a general increase in mineralization from the lower to the higher formations, the ore bodies in the late Paleozoic and early Mesozoic rocks of the Park City district being more valuable than any known in the earlier rocks of the Cottonwood area.

It is needless to say that this statement does not imply that valuable deposits do not exist in the Cottonwood-American Fork region, for several such deposits have been developed; but, so far as known, they are neither so large nor so continuous as those in the Park City district.

The greatest mineralization generally occurs toward the top of intrusive stocks or in the adjacent sedimentary formations at a corresponding horizon (see pp. 199–201), and therefore it is not probable that the mineralization in the Cottonwood-American Fork area was as extensive as that in the Park City district.

ALPINE DISTRICT.

By G. F. Loughlin.

The Alpine mining district is in the foothills of the Wasatch Range, north and east of Alpine, which is about 5 miles north of the town of American Fork. It includes the southwestern part of the Little Cottonwood granodiorite stock (see p. 239) and much of the great limestone series. Cambrian quartzite is also present but is not closely related to either of the two properties examined.

The only fissure deposit in igneous rock examined is that of the Lucky Chance mine,

[1] For a fuller discussion of the genesis see Part I.

[2] Boutwell, J. M., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, p. 128, 1912.

about 3 miles north of Alpine. The country rock is typical granodiorite. The ore occurs in shear zones along which the rock has developed a highly schistose structure. The shear zones strike N. 60° E. and N. 80° W. and dip 30°-60° N. They appear to be grouped in a belt of north-northeastward trend, 100 feet or more wide and of unknown length.

The mineralized rock consists principally of quartz that fills openings and more or less completely replaces the sheared rock, which is colored dark green by micaceous alteration minerals. The ore minerals are pyrite and galena. The deposits range from thin sprinklings along a fracture to well-defined lenticular veins as much as 1 foot wide and 20 feet long.

Thin sections of rock that is but moderately mineralized show greatly shattered feldspar and quartz as chief constituents. The feldspars are traversed by veinlets of sericite and calcite, and the large quartz grains by veinlets of minutely granular quartz. Chlorite in small drawn-out aggregates represents the original biotite of the rock. Pyrite in small grains is closely associated with the veinlets of sericite and quartz. The absence of magnetite suggests that its iron, with probably some from the biotite, has gone to form the pyrite. The sericite (if it is all of the potash variety) implies an introduction of potash to replace the soda and lime of plagioclase, but the principal materials introduced appear to have been water, carbon dioxide, and a little sulphur.

The more completely mineralized rock shows in thin section the same character, but the feldspar and chlorite are nearly all replaced, and the quartz is nearly all recrystallized. Secondary quartz is abundant and sericite subordinate. Galena accompanies the pyrite. Both ore minerals form aggregates, confined principally to the network of veinlets but also sending short branches into the inclosing minerals. The quantity of replacing minerals in this rock shows that silica, iron, and lead, as well as sulphur, water, and carbon dioxide, were introduced. Sericitization, characteristic of the less intense alteration, is here overshadowed by silicification.

A small shipment from this mine, made a few years ago, ran well in silver and comparatively well in gold.

The only deposit in the limestone of the Alpine district visited by the writer is on the Alpine-Galena property, near the mouth of Boxelder Canyon, northeast of Alpine. The country rock is near the base of the great limestone series and is probably of Cambrian age. The only ore found up to 1912 was in small masses of silver-bearing galena and lead carbonate along a bedding plane. The bedding plane has been followed down about 50 feet to a small body of leached replacement quartz originally pyritic.

The mineralization in the Alpine district, so far as disclosed both in the Lucky Chance and in the Alpine-Galena ground, was of the same character as that in the productive mines of the Cottonwood-American Fork region, but the amount was decidedly small.

SILVER LAKE DISTRICT.

By V. C. Heikes.

The Silver Lake district is in Utah County, 15 miles east of American Fork, on the Denver & Rio Grande and Los Angeles & Salt Lake railroads. The district was organized January 28, 1871. No records of early production are available. The period previous to 1880 is reviewed by Huntley,[1] who names the Milkmaid claim as the principal producer, with an output of $13,000. He says that the records showed 260 locations, of which not over 10 were held. He names the mines of the district as follows:

Mines of Silver Lake district.

Mines.	Total length of openings.	Total product.	Remarks.
	Feet.		
Milkmaid....	535	$13,000	Ore assays 36 per cent lead, 58 ounces silver, and a trace of gold; sells for $55.
Wasatch King.	370	500	Ore assays 11 ounces silver and 27 per cent lead.
Austin.......	700	None.	From 200 to 300 tons of ore and waste on the dump.
Nebraska.....	250	10 tons.	Ore assays 30 ounces silver and 35 per cent lead.

The total output of this district is included in the figures given for the American Fork district. (See p. 264.)

[1] Huntley, D. B., op. cit., p. 445.

PARK CITY DISTRICT.[1]

GEOGRAPHY.

Park City is on the eastern slope of the Wasatch Range, in the north-central part of Utah, about 25 miles southeast of and 3,000 feet above Salt Lake City and 7,000 feet above sea level. A branch line of the Denver & Rio Grande Railroad unites it by way of Parleys Park with Salt Lake City (35 miles), and a branch line of the Union Pacific Railroad extends from the main line at Echo (28 miles). It thus forms a most convenient outlet point for the producing mines on the slopes of the three canyons that lead southward from Parleys Park.

The Park City district lies between the precipitous cliffs and ledges that mark the main crest of the range and the verdant mountain meadows of Heber, Kamas, and Parleys that lie along its eastern foothills. The Park City quadrangle (see Pl. XXVII) contains, near the middle of its western border, the junction of the Wasatch crest with the Weber-Provo divide, which is the most prominent spur on the east slope of the central Wasatch and which forms a part of the boundary between Summit and Wasatch counties, and a connecting link between the Wasatch and Uinta ranges. This divide juts boldly forth from the main crest a mile north of Clayton Peak, and thence runs eastward for 3½ miles to the knob south of Bald Mountain, where it turns abruptly northward. The north-south part of the divide, together with a spur extending southward from the elbow, form a linear ridge that extends entirely across the quadrangle.

These main crests form the boundaries of three principal slopes, which drain to the east, south, and north, respectively. The long and gradual eastern slope, deeply incised by canyons, descends from the Bald Mountain ridge toward the intermontane lowland. The southern slope is occupied in great part by Bonanza Flat, the floor of an extensive glaciated basin, from which there is a steep acclivity to the crest of the Weber-Provo divide. The north slope, which lies in the elbow of this divide, is deeply cut by four narrow steep-sided gulches—Thaynes, Woodside, Empire, and Ontario—which drain to East Canyon Creek and the main branch of Weber River. On this slope lie Park City and the principal mines of the Park City district.

The climate is remarkably bracing, with short, cool summers, short autumns, and long, rigorous winters marked by heavy snowfalls and low temperature. Springs and watercourses cut by underground workings flow the year round, and natural rock basins at the foot of the pinnacle of Clayton Peak are utilized as reservoirs. Water for domestic purposes is obtained from the Alliance tunnel, and power for the Park City Electric Light plant from the Ontario drain tunnel. Water from the Snake Creek tunnel is also utilized for hydroelectric power. The slopes originally supported pine 3 to 5 feet in diameter, but to-day little heavy timber remains. Young aspen is common on canyon slopes, and the higher divides support patches of scrubby evergreens. Fuel is supplied from extensive veins of good coal at Coalville, 28 miles north, and from the forest growth on distant parts of the Wasatch and Uinta ranges.

MINING INDUSTRY.

HISTORY.

In the fall of 1869 locations in Little Cottonwood Canyon became so numerous that the Little Cottonwood mining district, with very nearly its present boundaries, was cut off from the somewhat extensive Mountain Lake district. Prospectors continued to spread into Big Cottonwood and American Fork, and some crossed the divide to the narrow gulches leading to Parleys Park.

When the first find was made is not certain, but the discovery of the Walker & Webster claim in 1869 by Rufus Walker and a subsequent find of ore the same summer by Ephraim Hanks are the earliest notices on record. The first location was the Easterly Extension of the Young America lode, made on December 23, 1868, and the next four were the Westerly Extension of the Young America lode, the Young America lode, the Yellow Jacket lode, and the Green Monster lode, all made in the following month. The first shipment of ore from this region, called in the records Parleys Park, is said to have been 40 tons for the month

[1] The description of the Park City district is largely abstracted from Boutwell, J. M., Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, 1912. Those desiring descriptions of the mines or more details concerning the geology are referred to that report.

of July, 1870.[1] Later records credit it to the Flagstaff mine. The Piñon mine in 1871 had a large body of galena and carbonate ores, said to assay 30 to 250 ounces to the ton,[2] and is said to have contracted to deliver 20 tons a day to a smelter to be erected at Ogden. In the same year the Flagstaff, Walker & Webster, Wild Bill, Rocky Bar, and other prospects were located. All are said to have been lead mines, principally carbonate, in limestone.

The increasing number of locations outgrew the supervision of the Mountain Lake district, which up to that time had included this area, and the Uinta (organized November 18, 1869), and the Snake Creek and Blue Ledge districts (established April or May, 1870) were set off from it. Parts of these three districts form what is now commonly known as the Park City district. The Uinta district lies in the southern part of Summit County and embraces all the present large mines in the Park City area; the Blue Ledge and Snake Creek districts are in Wasatch County and bound the Uinta district on the east and south, respectively.

In 1872, about two years after the first locations were made, the famous Ontario ledge was discovered. Rector Steen describes this discovery in these words:[3]

> I camped in a brush shanty for six months at the branch just below the Ontario, waiting for the snow to melt off. I went then to what is called the Badger mine, and about the 15th of June, 1872, we discovered the Ontario mine. There stood right near this mine a pine tree, and near by was a fine spring. We camped under this tree and got water from the spring. When we discovered this mine we found a little knob sticking out of the ground about 2 inches. * * * We had the rock assayed and it went from 100 to 400 ounces to the ton. We sold the mine to Hearst and Stanley on the 21st day of August, 1872, for $27,000. My partners were John Kain and Gus McDowell.

With the inception of the Ontario began an effort to mine lode ores. The Piñon, Walker & Webster, Flagstaff, McHenry, Buckeye, and other mines, some of which were discovered before the Ontario, had opened small ore bodies and had shipped small amounts of marketable ore from time to time, but in comparison with the Ontario none of them were conspicuous.

Machinery and some other articles had to be hauled 35 miles from Salt Lake City or 24 miles from Echo City, but fuel and timber were abundant.

The Marsac Co., which had bought the Flagstaff mine, and the McHenry Co. each built a stamp mill during the summer of 1874, but from lack of ore neither was largely used that year. The Ontario people then rented the McHenry mill and treated ore there in 1875. It also leased the Marsac mill but abandoned it on the completion of the Ontario 40-stamp mill. In the same year the first concentrator of the camp was erected to work over the Ontario tailings. In February, 1876, the Ontario mine alone was producing $14,000 a week, and the whole camp was producing $20,000.

The Daly Co. began work on the western extension of the Ontario vein; the tramway from the Crescent mine to the town was finished, and three or four small producers swelled the shipments of the camp. This renewed activity was enhanced by an advance in the metal market which aroused many old and abandoned mines carrying low-grade ore. As a result the producing area outside of the Ontario-Daly properties, which had hitherto been restricted to Crescent Ridge, became centered on Treasure Hill, which thenceforth rivaled the Ontario-Daly vein. For some years longer lode mining continued, but the activity on Treasure Hill was the beginning of mining bed ores, which continues still. In 1888 lode mining was given new life by the owners of the Ontario mine when they began its 3-mile drain tunnel. Their example was followed by the owners of the Anchor and Alliance mines. The passage by Congress of a law providing for the purchase of 4,500,000 ounces of silver a month greatly improved the silver market, increased the output of the Utah mines, and caused general prosperity.

In 1892, however, silver dropped to 83 cents an ounce—the greatest decline then on record. The effect on the annual output of Summit County was scarcely noticed, owing to the advent of two new producers, the Silver King and Mayflower; but it was seen in the passing of the Ontario dividend and the closing of the Crescent, Woodside, and Daly West mines. The production of silver in Utah steadily decreased after 1891, but that of Park City

[1] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1870, p. 223, 1872, quoted from a Salt Lake City correspondent.

[2] Idem, 1871, p. 329, 1873.

[3] Letter from Rector Steen to J. M. Boutwell dated Dec. 10, 1902. Steen was living in Missouri in 1902 in the enjoyment of good health, having left for his old home the day after the Ontario sale.

curiously increased till 1893, when it suddenly fell off. The mines of Park City worked only intermittently during that year; even the Ontario-Daly, which in 1892 was producing nearly three-fourths of the Park City product, fell off one-third. The year 1893 marked the beginning of cheaper methods, more effective saving, relief from water, and realizing from other metals besides silver, all of which aided greatly in raising the output of the camp.

In 1897 the price of silver dropped to 54 cents. In consequence the Daly West and Ontario mines closed down, but the silver-lead producers, of which the Silver King was the leader, were able to withstand the low metal market. Lower prices caused new economies in mining and reduction. Large concentration mills gave an increased capacity for low-grade ores. Rich smelting ore was discovered in Quincy ground in 1901 which quickly placed that property at the head of the list of producers, and the camp again assumed the lead in the production of silver in Utah.

In general the recent period has been one of continued mining of rich ores and an increase in the milling ores produced, which have been made profitable through improved methods of mining and metallurgy.

WATER SUPPLY AND MINE DRAINAGE.

Mountain lakes, springs, and mine openings afford sufficient and excellent water; and the large flows of water from the deep drainage tunnels furnish hydraulic power. Many of the mines have been very wet, and the handling of the water has been a great problem. In the early days pumping was used, but ultimately drainage tunnels were extended to progressively greater depth, culminating in the Ontario and Snake Creek tunnels.[1]

REDUCTION.

CHARACTER OF ORES.

The ores of the Park City mines are of both smelting and milling grades. Many large bodies of first-class ore have brought the camp its reputation for bonanzas. Recently, however, extensive bodies of low-grade ore have been opened, and more and more attention has been given to concentration.

[1] The history of the drainage problem is detailed in Boutwell, J. M., op. cit., pp. 24-26.

The Park City ores carry high contents of lead and silver with accessory gold and copper. The first-class ore is essentially sulphides of lead (galena), copper, and iron (tetrahedrite) with high accessory silver values. This combination together with carbonates and oxides constitutes the normal smelting ore.

The milling ores are made up of galena, pyrite, and zinc blende scattered through a quartz gangue. The silver lies in the pyrite and in the galena. Hence the problem in concentration is to save the galena and pyrite, together with any chalcopyrite and tetrahedrite which may be present, and to throw out silica and all the zinc blende in excess of the allowance. In practice difficulty is found in saving the silver, which tends to escape with the fines. Unusually high savings are now effected.

CONCENTRATION.

In a broad sense the milling of Park City ores falls into three periods characterized by different methods—the early experimental stage, relying chiefly on mechanical means; the intermediate stage, in which both chemical and physical methods were employed; and the third stage marked by the purely physical processes of modern wet concentration.

During 1874 and 1875 three 20-stamp mills were built and put into operation. All used simple devices for separation. The intermediate stage was marked by enlargement of the leading mills and by refinement and development of processes, dry crushing, chloridizing-roasting, and pan amalgamation being used. In 1880-1882 the Marsac mill was remodeled and fitted with dry kilns and water, and a process which was largely chemical was developed. Its inventor, Russell, in addition to extracting the silver by normal lixiviation methods after chloridizing-roasting, sought by new methods to produce bullion free from lead and to minimize or abandon the chloridizing-roasting. His process [2] consisted in general of (1) matting the sulphides in an iron pot; (2) roasting the pulverized matte in a muffle

[2] Stetefeldt, C. A., Russell's improved process for the lixiviation of silverores: Trans. Am. Inst. Min. Eng., vol. 13, pp. 47-118, 1885. Daggett, Ellsworth, The Russell process in its practical applications: Trans. Am. Inst. Min. Eng., vol. 16, pp. 362-495, 1888; Amalgamation at the Ontario mill compared with the Russell process at the Marsac mill: Eng. and Min. Jour., Mar., 1891. Stetefeldt, C. A., The Marsac refinery, Park City, Utah: Trans. Am. Inst. Min. Eng., vol. 21, pp. 286-298, 1892-93.

furnace; (3) dissolving the roasted matte in dilute sulphuric acid; (4) crystallizing from the solution bluestone which is used in the mill for preparing Russell's extra solution; (5) washing the silver residue, pressing it into cakes, and melting the dry cakes to bars.

While these two processes, lixiviation and amalgamation, were being thoroughly tried out the initial steps in the direction of modern wet concentration were being taken. "In a building near the Marsac mill and owned by that company four McKim concentrating machines were used successfully to concentrate both the tailings of the Ontario and the second tailings of the same mine after they had passed through the Marsac mill."[1] These pioneer machines originated at Park City and were patented February 15, 1876.

The Crescent Co., after endeavoring to smelt its ores without success, remodeled the old Crescent mill in 1886 and refitted it with additional machinery, including seven Frue vanners, two Huntington rolls, two Cornish rolls, and two rock crushers and screens, which raised its capacity to 100 tons a day.

In 1889 the Union concentrator was erected in Empire Gulch and equipped to handle 100 tons a day by the general method of modern wet concentration. It started in July and first ran on 10,000 tons of Woodside ore averaging $15 a ton. The Mayflower mill was built soon after in Woodside Canyon, and the Union mill, which had been running on custom ores, was gradually restricted to the Anchor ores.

The wet concentration process was so successful that it gradually supplanted the others, and during the nineties each of the great companies erected a large mill on its own property for the treatment of its own ores by this method. Each of these mills has been enlarged and remodeled more than once, and other mills have been built.

The Daly West mill was built in the middle nineties at a moderate cost and had a capacity of 50 tons a day. In 1900 it was remodeled and since then has been enlarged and rendered more and more efficient, until late in 1904 it treated 400 tons daily.

The Daly-Judge mill was built and then greatly enlarged in 1902 and subsequently remodeled without having run long on ore. It has a capacity of 500 tons a day and is the largest in camp. It does not differ in general plan and process from the Daly West mill described above.

The Silver King plant is the most complete and the most expensive in the district, and in equipment and efficiency is excelled at very few camps.

The mill erected at the Kearns-Keith property in 1903 is an exact duplicate of a single unit of the Silver King mill. The ore, however, differs considerably from that of the Silver King, being largely of milling grade and high in zinc. blende and iron. A fairly satisfactory concentrate was obtained.

In 1904, both the walls and the interior of the old Ontario amalgamation mill were remodeled and a modern plant for wet concentration was installed. The remodeled mill was started in February, 1904, with a small initial equipment, which was increased after some experimenting. In 1912 the capacity of the mill was 150 to 200 tons a day.

Smaller mills at other mines are run intermittently. The Comstock mill is reported to have a capacity of 120 tons. The equipment comprises a wet crusher, 3 cylindrical screens, 3 jigs, and 1 Huntington and 6 Wilfley tables. A small mill at the California mine comprises the equipment of the old Sampson mill with some additions and adaptations, and is understood to have given fair satisfaction in the treatment of the highly zinciferous ores. In Woodside Canyon just below the Silver King plant the old Mayflower mill has been run for a part of each year on old dumps and tailings. In Empire Canyon several small temporary plants from time to time rework the tailings from the Daly West and Daly-Judge mills.

TREATMENT OF ZINC ORES.

Numerous efforts to separate and to save the zinc have been made. Considerable zinc blende occurs in the sulphide ores, more particularly in those from the deeper parts of the veins and from the western section of the district. Among the large producers the only mines that yield rich zinc ore are the Daly West and Daly Judge. The average percentages of the main constituents in the concentrated ores of these mines, which consist almost

[1] Hantley, D. B., Tenth Census U. S., vol. 13, p. 441, 1885.

entirely of sulphides, are as follows: Daly Judge mine, lead 8 to 10 per cent, zinc 8 to 10 per cent, iron 6 to 10 per cent; Daly West mine, lead 4 to 6 per cent, zinc 6 to 8 per cent, iron 4 to 6 per cent. In 1904 the Ontario milling ore averaged 6 per cent zinc. The California and Comstock ores also carried much zinc.

The zinc blende (specific gravity, 3.9 to 4.1) usually occurs in a quartz gangue associated with pyrite (specific gravity, 4.95 to 5.1), galena (specific gravity, 7.4 to 7.6), and a small amount of chalcopyrite (specific gravity, 4.1 to 4.3). Gravity methods of wet concentration separate zinc blende from galena but will not separate it from chalcopyrite and pyrite, which too nearly equal it in specific gravity.

The particular characters of the respective ores also present special problems.

In August, 1902, a plant to save the zinc from the Park City ores was built by the Park City Metals Co. According to Mr. Glazebrook, its former superintendent, it embraced the old Peck concentrator building, roaster, and separator, and important new machinery. The equipment comprised one cylindrical furnace, a Howell and Hoyt roaster, a Hooc conveyor and magnetic separator, and six Wilfley tables. Over 1,000 tons were successfully treated by this process. It is stated that one lot of 35 tons ran 55 per cent zinc, that the average was about 52 per cent, that the product rarely fell to 48 per cent, and that in the ultimate rejection the tailings loss was not over 5 per cent of zinc. The plant burned to the ground in May, 1903, and the company being unable to obtain a renewal of its contract for middlings did not rebuild.

SAMPLING AND SMELTING.

The concentrates and crude ores from all the properties in the district are shipped for reduction to a custom smelter at Murray, 8 miles south of Salt Lake City. The ores from the Silver King mine are sampled at the mine and thence go directly to the smelter. The ores from all the other properties in the camp are sampled at the Park City sampler, on the northern boundary of Park City, and are then shipped to the smelter.

Since Boutwell's review of milling in the district (outlined above) was written the progress in milling has perhaps been most marked in the development of methods for the separation of a marketable zinc product and in the development of a chemical method of treatment of second-class ores of the Ontario mine that could not be profitably treated in the older mills.

The oil flotation process is now extensively used in the milling of the ores, and metallic zinc is being produced in the district by the electrolytic treatment of the ores.

METAL CONTENT OF ORES.

By V. C. Heikes.

The following synopsis of the character and metal content of the ores produced in the Park City district in recent years is compiled from the records of the United States Geological Survey.

DRY OR SILICEOUS ORES.

The dry or siliceous ores shipped to smelters from the Park City region are gold and silver ores carrying, on an average, very little copper and too little lead to be of value. The largest producer of this kind of ore has been the Ontario mine, which, for the greater part of the last decade, has been worked by lessees, who shipped considerable of the stope fillings. During 1913 and 1914 important quantities of silver bullion have been extracted in the mill by the Holt-Dern leaching process of chloridizing-roasting. The average of the ore treated is not included. The New York and American Flag properties were also important shippers of this class of ore. The quantity and average metallic contents of the dry ore shipped from the Park City region for each year during the last decade are as follows:

Quantity and average metallic contents of dry or siliceous ores produced in the Park City region and shipped to smelters, 1905–1917.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
1905	[a] 16,204	$0.30	5.13	....	1.53	$4.88
1907	2,477	5.46	39.01	....	.04	31.25
1908	1,990	7.69	24.62	0.24	1.00	22.22
1909	1,132	7.95	21.44	.17	.80	20.24
1910	2,713	7.26	25.50	.42	.64	22.67
1911	4,231	1.44	21.43	.02	.03	12.89
1912	1,032	1.18	24.81	.12	4.01	20.45
1913	1,635	.63	37.93	.51	4.24	28.85
1914 [b]	....	....	....	....	....	....
1915	2,750	.49	27.29	.04	1.52	15.90
1916	8,018	.56	25.38	.07	.60	18.45
1917	12,277	.64	29.74	.06	1.61	28.28

[a] Ontario stope fillings principally. [b] None.

COPPER ORE.

The copper ores include those carrying over 2½ per cent of copper. The Valeo and Odin properties have shipped most frequently. The average of these ores is as follows:

Quantity and average metallic contents of copper ore produced in the Park City region and shipped to smelters, 1906–1909, 1914–1917.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Average gross value per ton.
1906	166	$0.81	0.81	3.33	$14.23
1907	1,295	.87	.85	3.01	13.49
1909	57	.63	1.23	6.61	18.44
1914	16		1.87	1.55	5.10
1915	25	.66	1.08	3.78	14.36
1916 [a]					
1917	44		5.18	7.06	42.82

[a] None.

LEAD ORE AND CONCENTRATES.

In general the crude lead ores and concentrates are those that contain over 4½ per cent of lead. The regular shippers of this class of crude ore have been the Silver King Coalition, Daly-Judge, Daly West, Daly, and Silver King Consolidated and, in less degree, the Little Bell, Ontario, New York, Naildriver, Creole, Kearns-Keith, American Flag, Jupiter, Old Curtis, Revelator, J. I. C., Comstock, Wabash, Woodside, California, Kennedy Group, and Kennelly. Lead concentrates have come in recent years from the Silver King Coalition, Daly West, and Daly-Judge, and in earlier years from the California, Comstock, Ontario, Kearns-Keith, Little Bell, Kennelly, Daly, and Charles Moore. The quantity and average grade of the crude lead ore and concentrates is as follows:

Quantity and average metallic contents of lead ore produced in the Park City region and shipped to smelters, 1903–1917.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
Crude ore.						
1903	100,980	$2.37	54.76	1.40	27.85	$59.16
1904	91,871	2.27	45.88	.85	23.06	50.87
1905	51,338	4.42	47.17	.69	27.05	60.79
1906	59,743	2.56	41.36	.66	21.03	57.19
1907	46,854	1.98	35.53	.59	20.70	49.71
1908	32,105	1.59	52.82	.56	29.78	56.09
1909	41,521	1.15	43.16	1.51	30.49	52.25
1910	27,427	1.12	43.78	1.38	24.29	45.17
1911	38,358	1.19	43.65	.70	23.40	47.12
1912	30,987	1.06	55.30	1.59	25.32	63.11
1913	33,952	1.47	58.60	1.68	30.00	68.47
1914	37,326	1.62	49.74	1.57	24.98	52.79
1915	56,355	1.04	47.19	1.57	26.96	55.83
1916	43,238	1.76	46.51	1.29	23.36	70.96
1917	48,436	1.36	36.17	.77	20.53	70.63
Concentrates.						
1903	35,405	$2.10	44.60	0.95	31.08	$54.90
1904	34,173	2.15	46.79	.82	32.11	59.01
1905	31,897	2.26	45.60	.84	26.08	57.22
1906	36,600	2.40	32.85	.54	29.15	60.05
1907	34,105	1.95	29.98	.47	24.61	49.69
1908	25,061	1.54	28.58	.34	29.70	42.52
1909	30,941	1.12	29.19	.62	37.56	45.92
1910	34,473	1.04	30.67	.92	33.08	49.05
1911	47,906	1.01	31.85	.76	29.72	46.55
1912	39,768	.97	43.58	1.18	32.10	60.56
1913	34,356	.98	39.23	.88	30.09	53.89
1914	25,071	1.42	29.83	.67	26.70	40.54
1915	27,264	.84	31.20	.90	33.14	50.97
1916	23,618	1.24	27.11	.78	26.96	60.16
1917	27,278	1.31	25.90	.77	23.94	68.08

COPPER-LEAD ORES.

Copper-lead ores are classified according to the same method as the copper and the lead ores. The producers were the Columbus and Marie properties, in 1905 and 1906. The quantity and average grade of the ore shipped was as follows:

Quantity and average metallic contents of copper-lead ore produced in the Park City region and shipped to smelters, 1905–6.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
1905..........	10	\$2.10	55.00	3.50	13.50	\$58.70
1906..........	40	1.02	55.00	3.50	13.00	66.77

ZINC CONCENTRATES.

The zinc concentrates shipped are those usually containing over 25 per cent of zinc, but in the Park City region it had been the practice until 1912 to make a middling, which was re-treated at separator plants. The Daly-Judge mill has most frequently produced this kind of product, which, at first, was treated at a plant in north Salt Lake City, later at the Grasselli mill near Park City and at Midvale. Better concentration methods at the mills connected with the mines have allowed the shipment direct to zinc smelters. The loss of considerable zinc and some lead at the Park City mills caused the erection of many small plants during different years to re-treat the tailings lodged along Silver Creek. The producers of straight zinc concentrates with little lead were the Daly-Judge, Daly West, and Daly mines. The quantity and average grade of the zinc concentrates shipped is as follows:

Quantity and average metallic contents of zinc concentrates produced in the Park City region and shipped to smelters, 1905–1917.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Zinc[a] (per cent).	Average gross value per ton.
1905....	90	\$0.69	36.33	2.08	3.33	33.75	\$72.31
1906....	8,921	.50	8.22	......	......	18.77	29.00
1908....	3,153	.02	.81	......	.07	22.29	21.46
1909....	17,969	.42	5.14	......	2.03	17.58	23.85
1910....	8,162	.01	17.18	......	5.46	31.98	48.63
1911....	8,189	.19	4.80	.06	2.38	27.50	36.38
1912....	11,948	.25	13.72	.16	3.38	33.48	58.47
1913....	6,794	.23	18.19	.09	4.45	35.75	55.46
1914....	4,413	.35	13.39	.04	2.96	35.95	46.84
1915....	11,162	.36	14.19	.06	3.57	34.81	97.46
1916....	7,308	.36	11.62	.02	2.67	33.91	103.45
1917....	8,083	.24	14.21	.57	2.19	31.68	83.47

[a] Average assay represents recoverable zinc in middlings. Tonnage is net final product shipped to smelters.

LEAD-ZINC CONCENTRATES.

The lead-zinc concentrates shipped were usually brought to a higher degree at separation mills. The Daly-Judge and Daly West were the largest shippers. The quantity and average grade of the lead-zinc concentrates is as follows:

Quantity and average metallic contents of lead-zinc concentrates produced in the Park City region and shipped to smelters, 1905–1917.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Recoverable zinc (per cent).	Average gross value per ton.
1905....	3,794	\$0.47	9.06	......	4.76	25.19	\$40.20
1906....	375	.62	17.50	......	5.00	22.50	45.67
1907....	574	.22	16.37	......	4.04	22.54	41.92
1909....	1,084	.45	12.15	0.07	6.12	19.35	33.12
1910....	12,714	.45	8.19	.05	4.21	16.59	26.60
1911....	7,054	.03	13.97	.02	5.79	29.00	45.76
1914[a]..	......	......	......	......	......	......	......
1915[a]..	......	......	......	......	......	......	......
1916....	270	.45	11.63	.08	6.11	30.76	99.38
1917....	128	.32	7.50	......	5.50	31.26	79.82

[a] None.

PRODUCTION.

The following tables give the production of gold, silver, copper, lead, and zinc in the Park City district from the beginning of operations in 1870 to 1917:

Quantity of ore sold or treated in Park City mining region, 1870–1917, and metals recovered.

Year.	Quantity (short tons).	Gold.		Silver.		Copper.		Lead.		Recoverable zinc.		Total value.[a]
		Fine ounces.	Value.	Fine ounces.	Value.	Pounds.	Value.	Pounds.	Value.	Pounds.	Value.	
1870-1875 [b]				[c] 651, 300	$834, 377			[c] 2, 464, 000	$147, 840			$982, 217
1876				[c] 850, 000	986, 002			[c] 1, 500, 000	91, 500			1, 077, 502
1877				[d] 1, 310, 145	1, 572, 174			[c] 1, 800, 000	99, 000			1, 671, 174
1878				[d] 1, 112, 030	1, 278, 835			[c] 1, 750, 000	63, 000			1, 341, 835
1879				[d] 1, 041, 771	1, 166, 784			[c] 1, 500, 000	61, 500			1, 228, 284
1880				[c] 1, 252, 470	1, 440, 341			[c] 2, 940, 000	147, 000			1, 587, 341
1881		[d] 34. 00	$703	[d] 1, 931, 089	2, 182, 131			[c] 10, 074, 000	483, 552			2, 666, 386
1882				[c] 1, 934, 984	2, 205, 882			[c] 10, 500, 000	514, 500			2, 720, 382
1883		[d] 848. 00	17, 530	[d] 2, 011, 691	2, 232, 977			[c] 14, 725, 000	633, 175			2, 883, 682
1884		[c] 725. 00	14, 987	[c] 2, 167, 182	2, 405, 572			[c] 12, 329, 600	456, 195			2, 876, 754
1885		[d] 2, 222. 00	45, 933	[d] 3, 126, 890	3, 345, 772			[c] 16, 000, 000	624, 000			4, 015, 705
1886		[d] 2, 285. 00	47, 235	[d] 2, 881, 436	2, 852, 622			[c] 15, 000, 000	690, 000			3, 589, 857
1887		[d] 1, 959. 00	40, 496	[d] 3, 159, 453	3, 096, 264			[c] 14, 088, 000	633, 960			3, 770, 720
1888	[f] 63, 255	[d] 2, 561. 00	52, 941	[d] 3, 398, 126	3, 194, 238			[c] 15, 000, 000	660, 000			3, 907, 179
1889	[f] 77, 255	[d] 4, 171. 00	86, 222	[d] 3, 800, 266	3, 572, 250			[c] 19, 362, 000	755, 118			4, 413, 590
1890	[f] 76, 660	[d] 3, 055. 00	63, 152	[d] 3, 120, 063	3, 276, 066			[c] 18, 334, 200	825, 039			4, 164, 257
1891	[f] 88, 380	[d] 3, 450, 00	71, 318	[d] 3, 865, 510	3, 826, 855			[c] 23, 985, 600	1, 031, 381			4, 929, 554
1892	[f] 96, 603	[d] 4, 770. 00	98, 605	[d] 4, 078, 238	3, 548, 067			[c] 29, 148, 000	1, 165, 920			4, 812, 592
1893		[d] 2, 875. 00	59, 432	[d] 2, 709, 672	2, 113, 544			[c] 25, 172, 400	931, 379			3, 104, 355
1894		[d] 4, 451. 00	92, 010	[d] 2, 802, 289	1, 765, 442			[c] 16, 754, 020	552, 883			2, 410, 335
1895		[d] 4, 133. 00	85, 436	[d] 3, 204, 004	2, 082, 603			[c] 17, 475, 000	559, 200			2, 727, 239
1896		[d] 4, 377. 00	90, 471	[d] 3, 134, 820	2, 131, 678			[c] 28, 318, 400	849, 552			3, 071, 701
1897		[d] 5, 200. 00	107, 494	[d] 2, 737, 268	1, 642, 361			[c] 32, 762, 400	1, 179, 446			2, 929, 301
1898		[d] 6, 439. 00	133, 106	[d] 2, 215, 496	1, 373, 608	[d] 54, 609	$6, 772	[d] 33, 233, 553	1, 262, 875			2, 776, 361
1899		[d] 8, 803. 00	181, 974	[d] 3, 152, 329	1, 891, 397	[d] 805, 347	137, 714	[d] 41, 884, 755	1, 884, 814			4, 095, 899
1900		[d] 9, 093. 00	187, 969	[d] 3, 931, 205	2, 437, 347	[d] 703, 369	116, 759	[d] 46, 982, 647	2, 067, 236			4, 809, 311
1901		[d] 13, 731. 00	283, 845	[d] 7, 060, 623	4, 236, 374	[d] 2, 477, 080	413, 672	[d] 60, 232, 236	2, 589, 986			7, 523, 877
1902		[g] 15, 083. 00	311, 793	[g] 7, 990, 200	4, 234, 806	[g] 2, 869, 448	350, 073	[g] 69, 833, 456	2, 863, 172			7, 759, 844
1903		[g] 15, 317. 00	316, 631	[g] 7, 109, 209	3, 838, 973	[g] 3, 297, 101	451, 703	[g] 78, 243, 720	3, 286, 236			7, 893, 543
1904		[g] 13, 643. 00	282, 001	[g] 5, 814, 386	3, 328, 736	[g] 2, 118, 452	264, 804	[g] 64, 312, 559	2, 813, 674			6, 689, 215
1905	[g] 228, 142	[g] 14, 807. 00	306, 088	[g] 3, 998, 165	2, 414, 891	[g] 1, 254, 153	195, 648	[g] 45, 280, 817	2, 128, 198	[g] 1, 972, 327	$116, 367	5, 161, 192
1906	[g] 264, 792	[g] 11, 884. 67	245, 678	3, 755, 339	2, 516, 077	[g] 1, 194, 216	230, 484	[g] 46, 511, 176	2, 651, 137	[g] 3, 518, 139	214, 607	5, 857, 983
1907	[g] 235, 628	[g] 8, 413. 52	173, 923	2, 794, 552	1, 844, 404	[g] 945, 722	189, 144	[g] 36, 234, 757	1, 920, 442	[g] 258, 784	15, 268	4, 143, 181
1908	[g] 142, 331	[g] 5, 083. 34	105, 082	2, 463, 735	1, 305, 779	[g] 541, 061	71, 420	[g] 34, 051, 699	1, 430, 171	[g] 1, 405, 652	66, 066	2, 978, 518
1909	[g] 196, 172	[g] 4, 814. 18	99, 518	2, 825, 385	1, 469, 201	[g] 1, 655, 749	215, 247	[g] 46, 350, 390	1, 993, 067	[g] 6, 737, 237	363, 811	4, 140, 844
1910	[g] 215, 339	[g] 4, 467. 48	92, 351	2, 571, 771	1, 388, 756	[g] 1, 423, 629	180, 801	[g] 38, 129, 761	1, 677, 709	[g] 9, 437, 992	509, 651	3, 849, 268
1911	[g] 296, 350	[g] 4, 944. 12	102, 204	3, 428, 651	1, 817, 185	[g] 1, 281, 190	160, 149	[g] 47, 637, 642	2, 143, 694	[g] 8, 596, 564	490, 004	4, 713, 236

1912	[g] 280, 671	[g] 3, 664. 30	75, 748	3, 642, 749	2, 240, 290	[g] 1, 968, 249	324, 761	[g] 42, 111, 561	1, 895, 021	[g] 8, 001, 512	552, 104	5, 087, 924
1913	[g] 270, 527	[g] 4, 221. 00	87, 256	3, 717, 556	2, 245, 404	[g] 1, 794, 170	278, 096	[g] 41, 808, 713	1, 839, 584	[g] 4, 980, 206	278, 892	4, 729, 232
1914	[g] 236, 952	[g] 4, 797. 99	99, 183	2, 955, 008	1, 634, 119	[g] 1, 559, 953	207, 474	[g] 32, 323, 066	1, 260, 600	[g] 3, 173, 313	161, 839	3, 363, 215
1915	[g] 263, 342	[g] 4, 207. 66	86, 980	3, 754, 598	1, 903, 581	[g] 2, 287, 172	400, 256	[g] 49, 350, 377	2, 319, 467	7, 771, 350	963, 647	5, 673, 931
1916	[g] 300, 598	[g] 5, 381. 04	111, 236	2, 900, 718	1, 908, 672	[g] 1, 512, 578	372, 094	[g] 33, 233, 794	2, 293, 131	5, 136, 353	688, 272	5, 373, 405
1917	[g] 240, 610	[g] 5, 352. 51	110, 647	2, 937, 438	2, 420, 449	[g] 1, 285, 308	350, 889	[g] 33, 715, 565	2, 899, 539	5, 201, 756	530, 579	6, 312, 103
Total [h]	....	211, 263. 81	4, 367, 178	135, 299, 810	99, 202, 886	31, 028, 556	4, 917, 960	1,252,444,864	56, 374, 893	66, 191, 185	4, 951, 107	169,814,024

[a] Average commercial prices used for each metal to make total for each calendar year.

[b] In 1870–71 the Flagstaff, Pinyon, Pioneer, Buckeye, Walker & Webster, Wild Bill, and Rocky Bar deposits were discovered and were producers with the Ontario, discovered in 1872. The Ontario produced shipping ore in 1873 and 1874 and up to December, 1876, had yielded $1,100,000. See U. S. Geol. Survey Prof. Paper 77, pp. 136–137, 1912.

[c] Estimated by V. C. Heikes from a separation of the total output reported by the Director of the Mint or given in the annual reviews of the Salt Lake Tribune and the U. S. Geol. Survey Mineral Resources 1882–1897. Part of the records of some early producers were used in the estimates.

[d] U. S. Geol. Survey Prof. Paper 77, p. 36, 1912.

[e] Crescent and Sampson were the heaviest shippers of lead ores.

[f] Hanauer, A., jr., Mineral Industry, vol. 1, p. 185, 1892; see also reports of Director of Mint, 1888–1892.

[g] U. S. Geol. Survey Mineral Resources, 1902–1916.

[h] These totals are for mine output and aggregate more than if smelters' and refiners' figures were used.

Metals produced in the Park City mining region, 1870–1917, by periods.

Period.	Quantity (short tons).	Gold.		Silver.		Copper.		Lead.		Recoverable zinc.		Total value.
		Fine ounces.	Value.	Fine ounces.	Value.	Pounds.	Value.	Pounds.	Value.	Pounds.	Value.	
1870–1880	....	....	....	6, 217, 716	$7, 278, 513	....	....	11, 954, 000	$609, 840	....	....	$7, 888, 353
1881–1890	....	17, 860. 00	$369, 199	27, 531, 180	28, 363, 774	....	....	145, 412, 800	6, 275, 539	....	....	35, 008, 512
1891–1900	....	53, 591. 00	1, 107, 815	31, 830, 831	22, 812, 902	1, 563, 325	$261,245	295, 716, 775	11, 484, 686	....	....	35, 666, 648
1901–1910	....	107, 244. 19	2, 216, 910	46, 383, 365	26, 577, 997	17, 776, 611	2,562,996	519, 180, 571	23, 353, 792	23,330,131	1,285,770	55, 997, 465
1911–1917	1, 889, 050	32, 568. 62	673, 254	23, 336, 718	14, 169, 700	11, 688, 620	2,093,719	280, 180, 718	14, 651, 036	42,861,054	3,665,337	35, 253, 046
	....	211, 263. 81	4, 367, 178	135, 299, 810	99, 202, 886	31, 028, 556	4,917,960	1, 252, 444, 864	56, 374, 893	66,191,185	4,951,107	169, 814, 024

GEOLOGY.[1]

PRINCIPAL FEATURES.

The oldest rocks of the Park City quadrangle are sedimentary strata which range in age from lower Carboniferous to Triassic. They have been arched up to form a part of the eastward-pitching Park City anticline—a prolongation of the Uinta anticline—whose axis traverses the quadrangle from east-northeast to west-southwest, and they have been dislocated by many faults. They have been invaded, altered, and locally domed by diorite and diorite porphyry, which form the easternmost of the large intrusive masses that are exposed along the general course of the Park City anticline. The sedimentary and the intrusive rocks are overlapped on the east by the andesitic lavas of the intermontane trough.

The higher slopes, including the chief peaks and the valleys which radiate from them, bear evidence of local glaciation. The steep-walled amphitheaters or cirques which form the heads of these valleys contain much bouldery glacial drift. Below these cirques the valleys exhibit characteristic U-shaped profiles, ground and lateral moraines, boulder trains, perched erratics, striation, and scouring. The largest glacier of the district flowed southeastward from Bonanza Flat.

Each of the three main topographic divisions outlined on page 285 the north, east, and south slopes—differs from the others in geologic character. The north slope is chiefly formed of Pennsylvanian and Triassic strata, which dip northwestward at low angles and are intricately faulted. On the east slope the same strata occur with a general eastward dip; they are much intruded by diorite porphyry on the southern half of this slope and partly buried by andesite at the east. The south slope is occupied by diorite of the Clayton Peak mass, with its border of contact-metamorphosed sediments. These metamorphosed and hardened rocks stand up as the rugged backbone along whose northern side are found all the great bonanzas of the camp.

SEDIMENTARY ROCKS.

GENERAL FEATURES.

The sedimentary rocks of the Park City district include some of the upper part of the great limestone series of the region but belong mainly to five later formations, which range from Pennsylvanian to late Triassic or early Jurassic in age and have a total thickness of nearly 6,000 feet. The earliest of these formations is quartzitic; in the others the most abundant rock is shale, though a good deal of sandstone and limestone are present. The shale in the Mesozoic formations is mostly reddish where it is unaltered.

The best exposures of most of these rocks are found on the north side of Big Cottonwood Canyon, in the Cottonwood quadrangle, and the diagrammatic columnar section forming Plate XXIX is compiled from observations made at that locality.

CARBONIFEROUS SYSTEM.

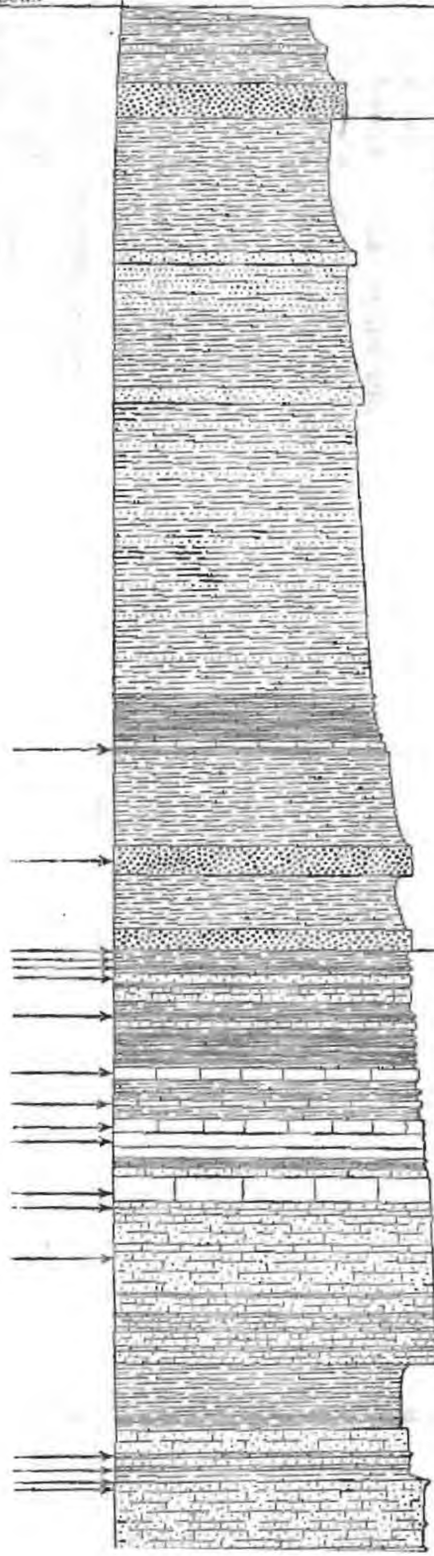
Undifferentiated limestones.—Some limestone masses of obscure stratigraphic relations and structure are mapped as "undifferentiated limestone." They occur chiefly in the southern and southeastern parts of the district. They consist partly of blue limestone containing little impurity, and partly of carbonaceous or sandy limestone. Much of the limestone is metamorphosed to coarse white marble. Some beds are known to be of Pennsylvanian age, because they are interstratified with Weber quartzite; others are shown by their fossils to be of earlier Carboniferous age, and belong to the post-Cambrian limestone series described on pages 238–239.

Weber quartzite.—According to Hintze[2] the Weber quartzite is unconformable on the underlying limestones, its base being marked by a conglomerate made up of rounded chert pebbles and silicified corals together with much fine material, but there is little or no angular discordance at the contact.

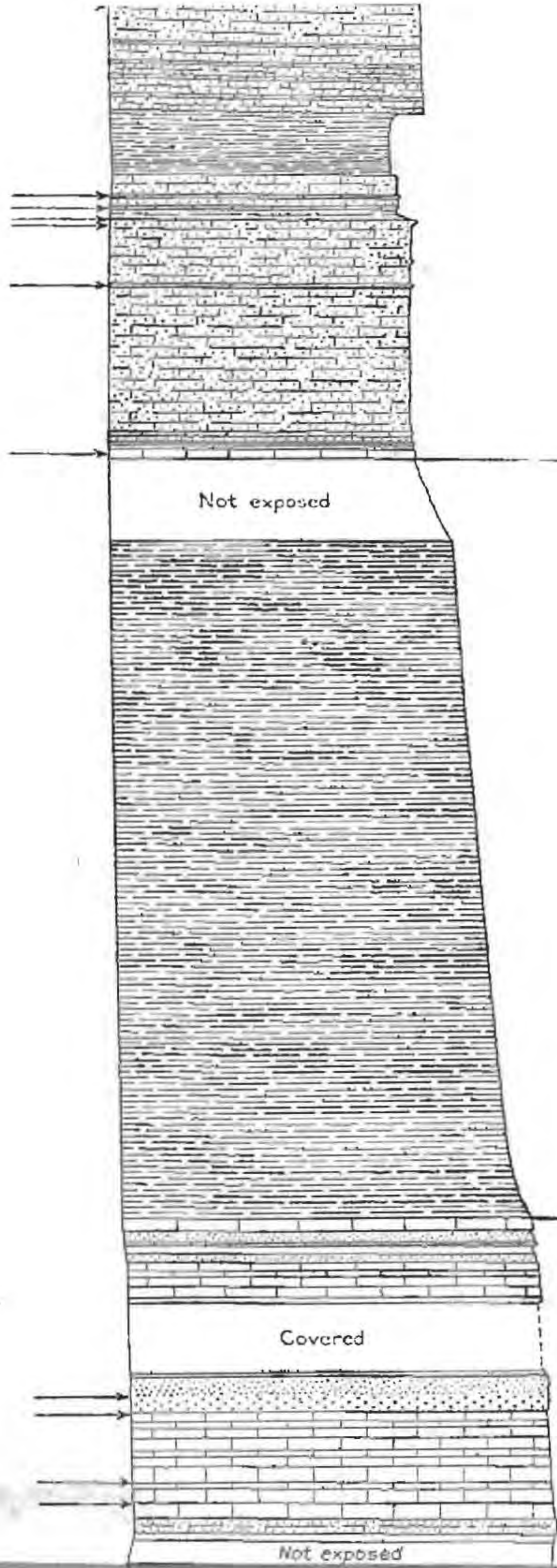
The Weber quartzite, whose thickness is given by Boutwell as 1,350 feet, consists mainly of quartzite but contains beds of limestone which are especially abundant near the base. The quartzite is generally thick bedded. On fresh fracture it is light brownish gray, and it weathers to a glittering surface of lighter shade. It is finer and more even grained than the Cambrian quartzite.

[1] Abstracted from Boutwell, J. M., op. cit., pp. 43–102.

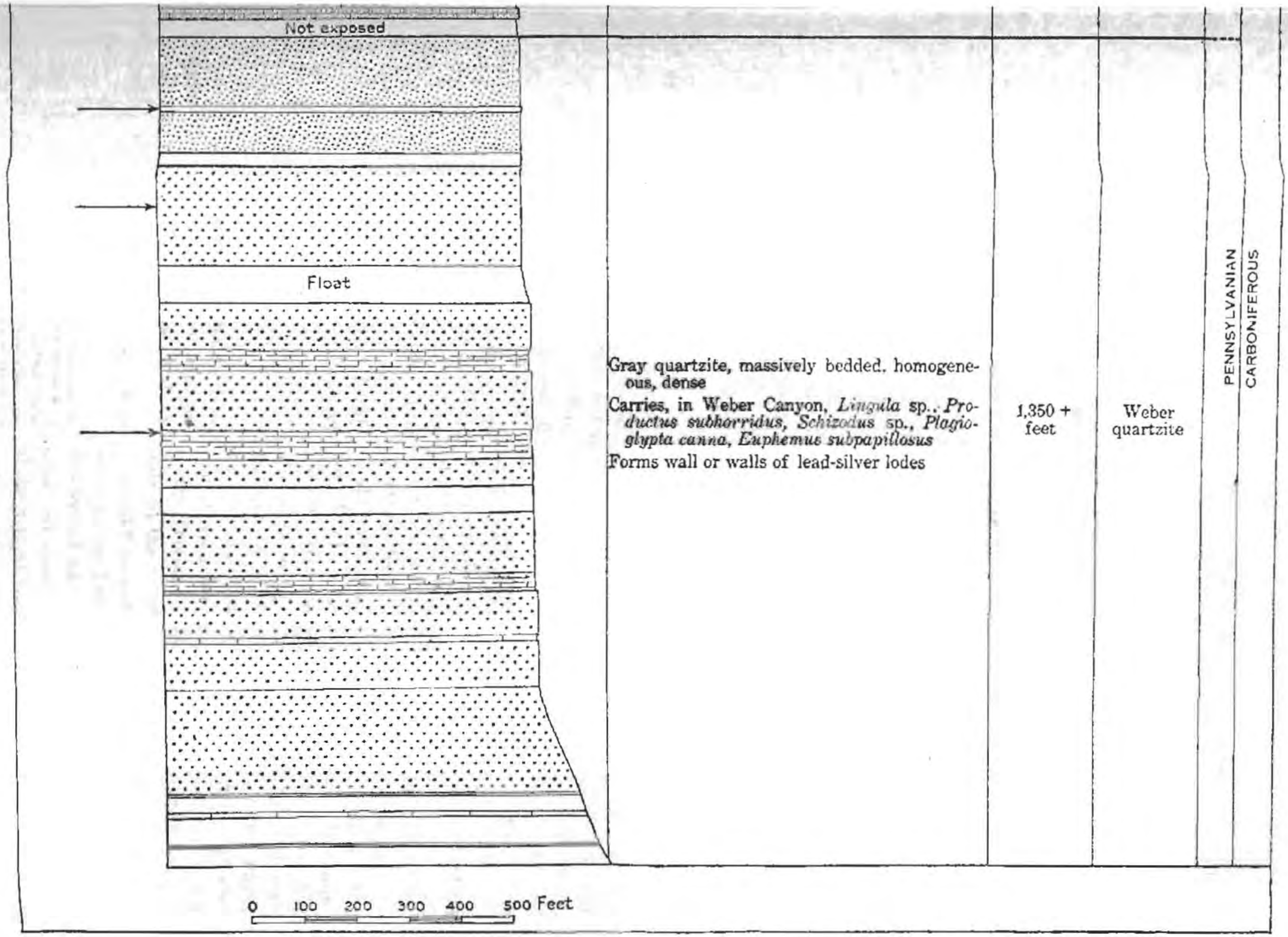
[2] Hintze, F. F., jr., A contribution to the geology of the Wasatch Mountains, Utah: New York Acad. Sci. Annals, vol. 23, pp. 113–120, 1913.



Fossil-bearing beds	Section and diagrammatic profile	Lithologic character	Thickness	Formation	Age
		White sandstones with intercalated red shales	500 +	Nugget sandstone	JURASSIC OR TRIASSIC
		Red shales, locally sandy, with interbedded coarse gray sandstones Carries in lower portion *Aviculipecten weberensis, A. curticardinalis, A. parvulus, Myalina permiana* No economic importance	1150 + feet	**Ankareh shale**	TRIASSIC
		Limestone, with sandstones and shales. "Mid-red" shale separates more calcareous upper from more arenaceous lower portion Carries large fauna, with numerous fossil species, chiefly pelecypods, including ***Pentacrinus*** **sp.,** ***Myalina permiana, M. aviculoides, Aviculipecten curticardinalis, A. weberensis, A. parvulus, A. occidaneus,*** **Lingulas, Spirifers,** ***Dentalia*** Forms country rock for replacement ore bodies and lodes	1190 feet	Thaynes formation	



red" shale separates more calcareous upper from more arenaceous lower portion Carries large fauna, with numerous fossil species, chiefly pelecypods, including *Pentacrinus* sp., *Myalina permiana*, *M. aviculoides*, *Aviculipecten curticardinalis*, *A. weberensis*, *A. parvulus*, *A. occidaneus*, Lingulas, Spirifers, *Dentalia* Forms country rock for replacement ore bodies and lodes	1190 feet	Thaynes formation	TRIASSIC
Red shale, thinly bedded, fine grained Bears ripple marks, mud cracks, raindrop imprints No direct economic importance	1180 feet	Woodside shale	
Limestone with interbedded quartzite, sandstones, and some shale Carries *Lingulidiscina* sp., *Productus cora*, *Productus* sp., *Plagioglypta canna*, *Euphemus subpapillosus*, *Bellerophon* sp. Forms country rock for principal bonanza replacement ore bodies	590 feet	Park City formation	PERMIAN ?



COLUMNAR SECTION SHOWING FORMATIONS PRESENT IN BIG COTTONWOOD CANYON.

After J. M. Boutwell.

The Pennsylvanian age of the Weber quartzite has been proved by the finding of Pennsylvanian fossils in the limestone beds, including some of the lowest, of the formation and in the overlying Park City formation.

The Weber quartzite is extensively exposed in the middle and eastern parts of the Park City district and in the northern part of the Cottonwood quadrangle.

Park City formation.—Although Boutwell recognized no unconformity between the Weber quartzite and the Park City formation, evidence of such an unconformity near Ogden is given by Blackwelder.[1]

The Park City formation, so named in recognition of its preeminent economic importance, occurs in the northeastern and eastern parts of the district. Its type section is on the north side of Big Cottonwood Canyon, where it has a thickness of 590 feet. The formation also occurs in two zones lying east and west of Park City respectively. It consists of limestone, sandstone, shale, chert, and phosphate rock. The limestone is mostly gray or blue. The sandstones and shales are prevailingly grayish and are in part calcareous. A bed of phosphate rock, which is dark and exceptionally heavy and has an oolitic structure, was noted by Boutwell[2] about 300 feet above the base, and probably other beds occur in the middle and lower parts of the formation. This bed has not been developed as an economic resource in the Park City district, but the Park City formation contains the great bulk of the phosphate that occurs in the western phosphate fields.[3]

The formation has yielded abundant fossils, which indicate that its lower part is of Pennsylvanian and its upper part of Permian age.

TRIASSIC SYSTEM.

Woodside shale.—The Woodside shale, about 1,100 feet thick, overlies the Park City formation unconformably, according to one of Boutwell's structure sections (DD', Pl. XXVII), though no evidence of this relation is given in his text. It is the most homogeneous formation in the district and consists almost entirely of dark-red shale, which bears abundant ripple marks, mud cracks, and raindrop impressions. It apparently contains no fossils, but it is regarded as Triassic because of its resemblance to certain members in the overlying fossiliferous Thaynes formation.

The Woodside shale forms two north-south bands, one in the northeastern and one in the north-central part of the district, and a long strip along the north side of Big Cottonwood Canyon. It has some indirect economic importance because of the vast amount of water that it carries.

Thaynes formation.—The Thaynes formation, about 1,200 feet thick, grades into the formations above and below, from both of which it is distinguished by its limy composition. It consists of limestone and of shale and sandstone which are in part calcareous. It is divisible into three members: the upper, which is 630 feet thick, contains the largest proportion of limestone; the middle, 120 feet thick, consists mainly of maroon shale; and the lower, 450 feet thick, contains abundant sandstone. A characteristic rock occurring at many horizons is a fine-grained calcareous sandstone, blue-gray and compact when fresh but porous and brown when weathered. Much of this rock is richly fossiliferous. The fossils in the formation prove its Triassic age.

The formation occupies a large part of the northern half of the Park City quadrangle.

Ankareh shale.—The Ankareh shale is 1,150 feet thick in Cottonwood Canyon. It resembles the Woodside in being dominantly red, but it is more sandy, and includes a number of well-marked beds of coarse gray sandstone, which range from 20 to 55 feet in thickness. It also comprises a few thin beds of limestone, which carry Triassic fossils. The formation occurs only in the northwestern part of the district.

Nugget sandstone.—The highest strata that occur in the Park City district consist of about 500 feet of white sandstone, interbedded with a little red shale, which represent the lower part of the Nugget sandstone. The age of the formation is not certain, but it is either Triassic or Jurassic, for fossils prove that the formation

[1] Blackwelder, Eliot, New light on the geology of the Wasatch Mountains: Geol. Soc. America Bull., vol. 21, p. 532, 1910.

[2] Idem, pp. 113-114.

[3] See Gale, H. S., and Richards, R. W., Preliminary report on the phosphate deposits in southeastern Idaho and adjacent parts of Wyoming and Utah: U. S. Geol. Survey Bull. 430, pp. 457-535, 1910; Blackwelder, Eliot, Phosphate deposits east of Ogden, Utah: Idem, pp. 536-551; and Schultz, A. R., A geologic reconnaissance of the Uinta Mountains, northern Utah: U. S. Geol. Survey Bull. 690, pp. 31-94, 1918 (Bull. 690-C).

below is Triassic and the one above Jurassic. The Nugget sandstone is exposed in the extreme northwest corner of the Park City quadrangle.

IGNEOUS ROCKS.

TOPOGRAPHIC OCCURRENCE.

Igneous rocks occupy nearly one-third of the area of the Park City district. In distribution they coincide in general with the productive area and in occurrence they are intimately associated with ore bodies. The three petrographic types (diorite, diorite porphyry, and andesite) occur in distinct areas.

The diorite forms the most rugged and precipitous ridges and the loftiest summit in the region—Clayton Peak. (See Pl. XXX, *B*.) The generally homogeneous character of the rock, the absence of dominating structure planes, and the presence of readily removed mineral constituents have combined to permit deep and characteristic dissection. The eastern margin of this mass, with the single exception of an arm in the gap above the head of the Daly-Judge shaft, is covered by the extensive glacial deposits of Bonanza Flat.

Rising from beneath this covering on the east and northeast are extensive irregular masses of coarse diorite porphyry, which stretch eastward and northeastward for nearly 4 miles, surrounding Bald Mountain in the form of dikes and small stocks. This rock weathers somewhat easily and forms broad flaring saddles or gaps on divides, as at the head of Empire Canyon near the Lucky Bill shaft and east of the Little Bell shaft on the northern slope descending from Flagstaff Mountain. On the southwest slope of Bald Mountain it yields a coarse, loose sandy soil.

On the adjacent northeast and the extreme southeast and lying about the eastern foothills of the range are parts of the great extrusive mass of andesite, which floors the valley between the Wasatch and Uinta ranges. The surface of that portion of the extrusive mass which appears within the Park City area slopes gently eastward away from the Wasatch and is cut by numerous shallow gullies into parallel strips.

QUARTZ DIORITE.

Quartz diorite occurs in a general oval area, which extends from the head of Big Cottonwood Canyon eastward in the upper basin of Snake Creek for over 3 miles and from the head of Snake Creek northward for 2 miles, forming the main divide of the Wasatch. It thus forms the easternmost of the three great igneous masses in the main zone of intrusive rocks of the middle Wasatch and occupies the southwestern portion of the Park City district. It cuts across sediments at the heads of the northwest tributaries of Snake Creek and of Big Cottonwood and is buried on the east by the glacial deposits of Bonanza Flat. Farther east it forms the broad tongue in the gap above the Daly-Judge tunnel, and small portions of its contact appear along the main road in Bonanza Flat immediately east. The best exposures were found along its northern and southern contacts.

Analyses of quartz diorite.

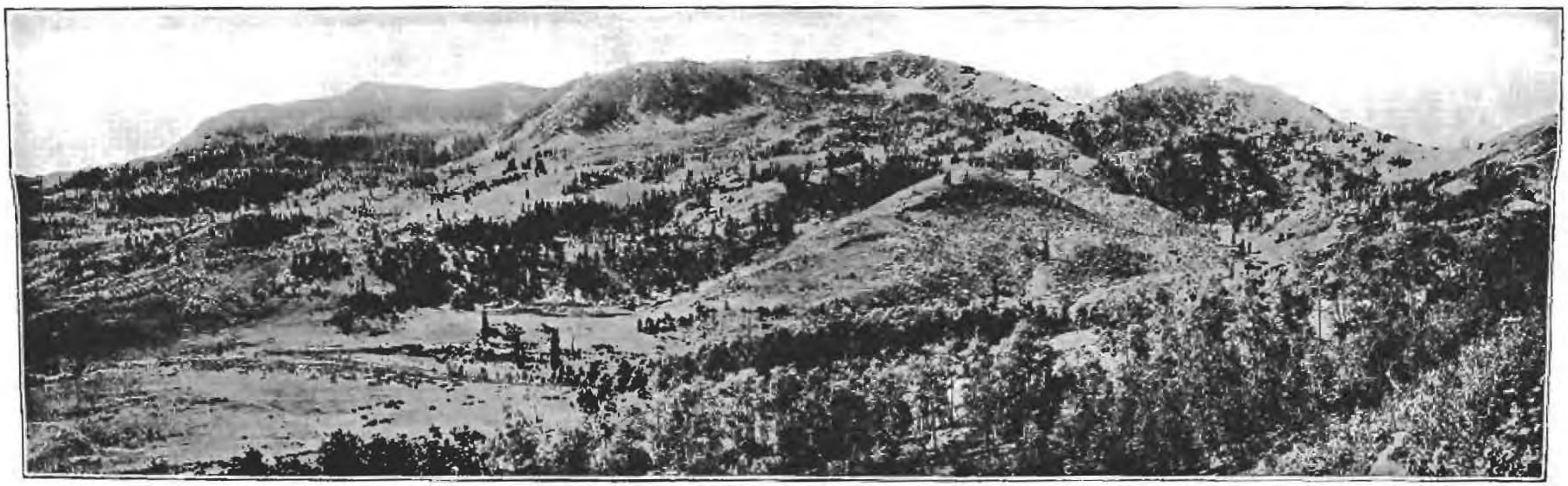
	1	2
SiO_2	59.35	63.46
Al_2O_3	16.36	15.93
Fe_2O_3	2.90	2.61
FeO	3.36	2.31
MgO	3.08	2.27
CaO	5.03	4.33
Na_2O	3.73	3.66
K_2O	3.85	3.49
H_2O-	.28	.27
H_2O+	.64	.74
TiO_2	.87	.62
ZrO_2	.03	.03
CO_2	Trace?	Trace.
P_2O_5	.44	.16
SO_3	None.	None.
Cl	.05	.05
F	(?)	Trace?
FeS_2	.02	[a](0.01 S)
Cr_2O_3	None.	None.
MnO	.07	.09
BaO	.16	.15
SrO	.05	[b]
Li_2O	Faint trace.	Faint trace.
ZnO	.01	....
CuO	.01	....
	100.29	100.17

[a] Trace from pyrrhotite. [b] Included in CaO above.

1. Quartz diorite, three-fourths of a mile northeast of Clayton Peak. W. F. Hillebrand, analyst.
2. Quartz diorite, east side of Brighton Gap. W. F. Hillebrand, analyst.

Hand specimens show a fine even-grained rock composed of a uniform mixture of light and dark minerals. New fractures generally present a bright, fresh appearance. The light minerals are chiefly white feldspar. Some pinkish feldspar is mingled with the white, and rarely quartz may be recognized. Of the dark minerals, glistening flakes of black biotite are

A. PARK CITY MONOCLINE.



B. CLAYTON PEAK DIORITE STOCK.

most noticeable, and the dull greenish-black color and lath shape of hornblende is less so. All are about equal in size, few exceeding one-eighth of an inch.

QUARTZ DIORITE PORPHYRY.

Diorite porphyry is the largest and most widely extended of the igneous formations. Most of it lies in the eastern and southern parts of the district, but a few small isolated bodies occur at the west and northeast. All the large areas and nearly all the exposures appear to be united on the surface into a single extremely irregular body which, except for a narrow junction on the east, is roughly separated by the quartzite on Bald Mountain into two parallel masses. The southern and major member extends from the extreme head of Empire Canyon in the region of the Daly-Judge, Daly West, Quincy, and Little Bell mines eastward and southeastward to its junction with the northern mass east of the Valeo mine, in Cottonwood Canyon. It is well exposed by the broad, shallow amphitheater and saddle at the south head of Empire Canyon and is characteristically developed in the main bodies which extend eastward and southward, in the irregular connecting dikes around the eastern wall of Bonanza Flat and about the heads of Durey and Pine canyons. From the connecting neck in Cottonwood Canyon the northern mass extends northward and northeastward around Bald Mountain, crossing Glencoe, Wasatch, and McHenry gulches, and an arm reaching northward enters McCune Hollow. Owing to the exceeding difficulty of tracing outlines on precipitous slopes amid dense scrubby growth the boundaries that are shown on the map necessarily fall far short of expressing the extremely irregular outlines of these masses.

The major part of this porphyry takes the form of irregular stocks and dikes issuing from the stocks. A few sills are present. The principal stocks are the elongated, roughly rectangular masses just south and east and northeast of Bald Mountain. Smaller masses lie at the head of Empire Canyon and between Bald and Bald Eagle mountains.

The usual appearance of the diorite porphyries of the Park City district in the outcrop is that of light-gray, faintly spotted rocks, but on fresh fracture the phenocrysts stand out more distinctly in a dark groundmass. Close examination shows that the color of the rock lies in the groundmass, which runs through shades of drab or deep bluish or greenish gray. It is also seen that the phenocrysts are not confined to the light feldspars but include indistinct crystals of the dark ferromagnesian minerals—hornblende, biotite, and, rarely, augite. In some fresh specimens the shining facets of the feldspars are striped with the multiple twinning of the plagioclases, and in others, especially in altered samples, may be discerned fragments of rough greasy quartz. The groundmass even under a hand glass appears to be no more than a fine crystalline mass of ill-formed minerals. Among these may be recognized with difficulty particles of biotite, feldspar, and pyrite.

The phenocrysts vary widely in size. Few are over half an inch in greatest length. Relatively the plagioclases develop the largest phenocrysts; next rank the hornblendes, which rarely attain a length greater than a quarter of an inch; finally the dark-brown micas, which here and there outmeasure the hornblendes but very generally are smaller in diameter though equivalent in area. Quartz, where it occurs as phenocrysts, very rarely measures more than an eighth of an inch in diameter, and augite is scarcely ever noticeable.

Two analyses of the diorite porphyries have been made and are given below, one from the ordinary variety typical of this district and another from a more quartzose phase.

Analyses of quartz diorite porphyry.

	1	2
SiO_2	59.68	61.64
Al_2O_3	15.61	14.66
Fe_2O_3	2.49	1.95
FeO	2.38	1.68
MgO	2.52	2.55
CaO	4.63	4.65
Na_2O	3.96	2.71
K_2O	2.92	3.07
H_2O	2.51	3.60
TiO_2	.62	.48
ZrO_2	.01	.01
P_2O_5	.29	.24
CO_2	2.29	2.15
FeS_2	.02	.32
MnO	.08	.06
BaO	.15	.18
SrO	.07	.06
	100.23	100.00

1. Quartz diorite porphyry from dike northwest of Daly West shaft. W. F. Hillebrand, analyst.
2. Quartz diorite porphyry from Valeo mine. Cottonwood Canyon. W. F. Hillebrand, analyst.

These analyses rank well toward the acidic end of the diorite group, being high in silica. Probably one-third of the specimens contain enough quartz to be ranked with No. 2 of the table.

ANDESITE.

The two small portions of the great extrusive mass of andesite on the east afford good evidence as to its general characteristics. They lie in the extreme northeast and southeast corners of the region mapped, at the eastern base of the range, and embrace an area barely a mile square. The great expanse of these rocks which stretches eastward for about 8 miles to Kamas Prairie and northwest and southeast for about 30 miles shows high rugged hills rising 1,000 to 2,000 feet above its western margin in the Park City district. If the upper surface of these extrusive masses were originally level, the present lower elevations of its western portions which now wrap about the eastern flanks of the Wasatch Range must be due to denudation.

Low gullies cut deeply into the extrusive mass and show it to be made up of layers of varying destiny, coarseness, and massiveness. Some were clearly formed as flows, others as beds of bomblike bodies, possibly ejectamenta. All incline to the east.

In several of the transverse valleys in the West Hills sandstone and quartzite crop out from beneath the andesitic blanket and afford some clue to the ancient topography. The eastern dip from the flanks of the Wasatch Range and the western dip of certain beds in the eastern part of the area suggest the early valley form, although possibly the Wasatch has risen since the extrusion and imparted the easterly inclination.

The andesite is a decidedly speckled pinkish or greenish rock, commonly gray on fresh fracture. In hand specimens these colors seem confined to a dense fine-grained groundmass, in which are sprinkled phenocrysts of feldspar, hornblende, and mica.

Of the phenocrysts the feldspars seem to predominate, with smaller amounts of hornblende and still less biotite. In places they are arranged in parallel lines significant of rock flowage. Both phenocrysts and groundmass usually lack the lustrous appearance which characterizes a fresh rock. Some of the feldspars, however, have still retained fresh glassy faces on which may be distinguished the multiple twinning lines of plagioclase. The feldspars are the largest of the phenocrysts, ranging in size from one-fourth of an inch to small grains. Hornblende crystals are more uniform and are as a rule not longer than one-eighth of an inch. Biotite ranges between these two minerals. Rarely a few quartz grains may be recognized.

All phenocrysts grade into the groundmass, which is macroscopically very dense and indeterminate.

The general color of much of the rock is mottled, owing to change in texture, which indicates that the rock is composed of fragments in an andesitic matrix. All fragments, however, contain the same essential minerals as the matrix in like proportions, and the whole may be called andesite breccia.

A chemical analysis of the andesite is given on page 90.

The percentage of silica is somewhat low for rocks in this class, but the proportions of other elements are medial. From its mode of occurrence, mineralogic character, and chemical composition the rock seems to belong with the andesites.

ANDESITE TUFF.

The tuffs from the Park City district are gray to yellowish-gray rocks composed of white, yellow, and black particles, in places resembling a poorly compacted fine sandstone, from which they grade into a very soft, flaky, somewhat argillaceous rock containing larger grains. Specimens from the lower parts of the mass are somewhat laminated; but the laminations seem due rather to flowage, as in mud flows, than to water sorting, for the bedding lines are not distinct and the particles vary greatly in size. The rocks have, however, the appearance of rather even fineness, the grains averaging one-fifth of an inch in size and being loosely cemented together. The bright, fresh appearance of a crystallized rock is lacking. The constituent grains are too small to allow definite determination, though from the abundance of whitish and yellowish particles it may be surmised that considerable feldspar and probably quartz are present.

In addition to the main types described, there are numerous granitic and a few peridotite dikes in the district.

GEOLOGIC RELATIONS.

Relations of igneous masses to one another.—The relative age and other geologic relations of the three principal igneous masses have not been proved. The diorite has not been observed to cut or be cut by the diorite porphyry; and no conclusive field evidence as to the geologic relation of the diorite porphyry and the andesite has been found. No actual passage of porphyry as an intrusive upward and out into andesite as an extrusive, thus indicating contemporaneity, was observed. On the western margin of the extrusive area, however, fragments and a considerable oval area of porphyry are included in the andesite and would thus appear to be earlier. Further, this porphyry proves to be petrographically the same as the perfectly characteristic facies that outcrops near the Valeo mine. If this porphyry is earlier and is contemporaneous with the Valeo rock and the other porphyries of the district, then the porphyry as a whole is older than the andesite. Furthermore, the andesite fills, wraps around, and blankets an old topography which to every appearance was developed on the porphyry after its intrusion. It is therefore probable that the andesite not only is later than the diorite porphyry but was extruded after the porphyry had been extensively eroded

Relation of igneous rocks to sediments.—The intrusive rocks, quartz diorite and quartz diorite porphyry, cut all the consolidated sedimentary rocks with which they are in contact. The andesites rest upon Eocene ("Vermilion Creek") sedimentary rocks and the lower tuffs grade into the sedimentary series. These relations indicate that the diorite is not earlier than Triassic, that the porphyry is at least as late as early Triassic, and that the andesite is later than the "Vermilion Creek" (Eocene).

STRUCTURE.

The formations in this area constitute an anticline that trends somewhat east of north and west of south and that pitches northeast. This broad arch is modified by strong faulting and minor local folding, some of which was very likely caused by intrusions. (See Pl. XXVII.)

FOLDING.

The Park City arch, comprising all the sedimentary formations, embraces the entire area. It is broad and low, the formations on its flanks dipping gently northwest, east, and southeast, and its axis gently northeast. The western limb includes the formations from the Weber quartzite to the Nugget sandstone, inclusive, and forms a structural unit as a monocline. The dip averages 35° NW. Just north of Park City the strike of the beds gradually swings eastward, and northeast of the city the upper formations disappear beneath extensive flows of andesite. All reappear, however, striking southward and passing down the east side of the area to form the eastern flank of the Park City anticline.

A few minor folds on this major fold are, as a rule, directly traceable to local deformation, which has caused many fractures. Thus, west of Jupiter Hill, along the south side of the divide, the metamorphosed beds appear to form a shallow trough broken along a fracture zone opened through the Jupiter mine and marked by the first strong gap in the divide west of Jupiter Peak. Crumpling was noted at the head of Thaynes Canyon, on the west side.

On the eastern limb the local deformation was apparently greater. At the north, along the east side of Deer Valley Meadow and Frog Valley, two areas show disturbance in strike and dip. North of upper Drain Tunnel Creek, in an angle between faults, the beds are somewhat disturbed; east and southeast of the head of Frog Valley they are much disturbed, contorted, and broken; in the extreme southeast corner of the area mapped, the formations show some crumpling and folding and some local breaks; and elsewhere local crumpling, steep tilting, and irregular contorting has been found.

FAULTING.

Six important zones of faulting have considerably modified the continuity of the Park City anticline. These include on the west side the Ontario and Daly West, the Crescent, and Massachusetts fault zones, and on the east the Frog, McHenry, and Cottonwood zones. No adequate and satisfactory correlation of these is apparent.

The Ontario and Daly West fault zone is known along its strike for 2 miles from a point on the surface immediately west of the Parleys Park shaft to an underground point considerably west of the Daly-Judge shaft and in depth for 2,000 feet in the Ontario and 2,100 feet in the Daly West. It is a strong zone of fractures ranging from single definite fissures

to broad zones of brecciation, and the main Ontario fissure ranges in width from a few inches to a hundred feet. Its prevailing strike is N. 60° E. and its average dip is 70° NW. Structurally it is a great fault whose hanging wall has relatively dropped. The amount of displacement could not be precisely determined but was probably 230 feet just west of the Ontario No. 3 shaft and approximately 350 feet on the Daly West branch. It is later in date than the intrusion of the diorite porphyry and earlier than certain northwest faults. The economic effects of this dislocation has apparently been a relative elevation of the ore-bearing limestone members. Westward it is highly probable that the gap and decided offset in the main divide above the Daly-Judge shaft are due largely to this great fault zone.

The Crescent fault zone is known in the Daly-Judge drain tunnel on the east and considerably beyond the crest of Crescent Ridge on the west, thus extending for at least 9,000 feet. Its most prominent outcrop is at the junction of Crescent Ridge and Pioneer Ridge, where the Nugget sandstone and Ankareh shale are dropped into juxtaposition with the Thaynes formation. At this point the trend is slightly north of east and the dip apparently very steeply north. To the east the bedrock in the course of this fault is heavily blanketed with glacial material. Beyond, along the west wall of Empire Canyon, the Thaynes formation, equivalent to that on the north side of the fault zone in Crescent Ridge, reappears in prominent bluffs which continue southward. Clearly this is a great fault, and the apparent lateral offset to the west on the north side measures about 3,000 feet. The same displacement has undoubtedly separated the ore-bearing limestone of the Daly West from that in the distant Silver King mine, the two limestones belonging to one and the same formation.

Just north of this zone, at the collar of the old Massachusetts shaft, the Massachusetts fault is well defined between Weber quartzite on the north side and limestone and sandstone of the Park City formation on the south. It strikes N. 70° W. and stands about vertical. Although much obscured by glacial drift, it may be traced on the surface by isolated outcrops of limestone of the Park City formation on the south and of Weber quartzite on the north for about 3,000 feet. Underground it is well shown in the Daly-Judge tunnel, and especially in the Alliance tunnel, where it strikes N. 70°-75° W. and dips 68°-70° S. Although not positively identified in the Silver King mine proper, it is believed to have been cut by the King-Alliance connection. It has offset boundaries about 2,500 feet to the west on the north side. With the Crescent fault, it outlines an east-west wedge of sediments which has apparently been offset to the west.

In the northeastern part of the district the topography and the distribution and structure of formations give evidence of the great Frog Valley fault. Along the east side of Deer Valley meadow the Park City formation rises abruptly from the flat meadow bottom, the contact between limestone and the quartzite being concealed by alluvium. On the north, in the vicinity of the Cincinnati group and northward, a north-south fault has relatively raised the Weber quartzite on the west or moved the Park City formation southward on the east. Farther south, along the eastern upper slopes of Frog Valley, a strong north-south fracture is exposed in a gully with Woodside shale on the east and Weber quartzite on the west. On the south, about 100 feet above the valley, the fault divides and includes a narrow lens of Park City formation. Still farther south the fault continues around the eastern slope of Bald Eagle Mountain, with Thaynes formation on the east and Weber quartzite on the west. The course of the main fault around Bald Eagle Mountain, curving eastward, indicates that the plane of dislocation dips about 45° W., and this is corroborated by conditions in the Ontario drain tunnel. The fault could not be found south of the bottom of McHenry Canyon, nor could its actual relation with the McHenry fault be observed.

These facts indicate a great compound overthrust fault. The west side has ridden up over the east side for many hundred and probably for more than 2,000 feet. On the east side of Bald Eagle Mountain the Weber quartzite laps up into contact with the Thaynes formation, concealing the entire Park City and Woodside formations. Economically, the recognition of this overthrust fault extends exploration beyond previously known limits of the ore-bearing Park City formation into regions

of favorably fractured intrusion and metamorphism.

Another great fault, the McHenry, of different type but quite as extensive, lies immediately south of the Frog Valley fault. This fault is traceable eastward along McHenry Canyon from a point about half a mile below its head to a point about 2,000 feet east of the Liberty tunnel, a total distance of a mile. The actual fault plane appears at the surface where opened just east of the Hawkeye shaft as a zone of intense brecciation striking east-northeast and dipping 45° N. between metamorphic limestone on the north and massive quartzite on the south. On the east it is marked by scattered quartzite ledges and a contact between metamorphic limestone of the Thaynes formation and Weber quartzite. Underground it has been opened for many hundred feet in the Lowell, McHenry, and Hawkeye mines. Much of these mines is inaccessible, but in portions of the Hawkeye the McHenry fault appears as a zone of intense fracturing and brecciation striking east, with a width ranging from a few inches to 170 feet but averaging a few feet. The hanging wall is commonly metamorphic limestone, though for many hundred feet on one level it is quartzite; and the footwall is quartzite, some metamorphic limestone, and porphyry. At one point well-defined slickensides pitch 45° SW. The general effect of this great fault has been to offset the formation boundaries on the south side eastward for at least 2 miles.

The Cottonwood fault lies in the extreme southeastern part of the district, in Cottonwood Canyon, from which it is named. About 4,000 feet southeast of the Valeo mine the eastern wall of Cottonwood Canyon is interrupted by a low saddle, which marks a fault contact between Weber quartzite on the north and Woodside shale on the south. The fault has been followed along a sinuous east-west course for about 4,500 feet. Its effect has been to shift the formation on its north side toward the east for about 4,000 feet. It may thus be regarded as a smaller companion fault to the McHenry, the two inclosing between them a wedge which has moved relatively eastward or upward.

DEFORMATION BY INTRUSION.

The injection of great bodies of diorite and diorite porphyry into the sedimentary rocks obviously caused intense deformation. Whether the engulfing and absorption of portions of the invaded sediments by the intrusive magmas was large or small, the compressive force exerted on the sediments was, even if rated at its minimum, very great.

The introduction of the Clayton Peak mass, which probably entered the lower portion of these sediments only, without reaching the surface, doubtless domed the overlying Triassic and Jurassic sediments.

The invasion of the Carboniferous formations by diorite porphyry magma, apparently forcing its way irregularly northeastward, would seem to have been accomplished under very high pressure. Deformation directly traceable to it is seen in several places. Two miniature examples will suffice to prove its existence and to show its nature, and thus point the way for detecting similar effects on a larger scale.

In the Silver King mine, on the 1,100-foot level, the main crosscut south has exposed tongues of diorite porphyry extending upward into calcareous sandstone. Aside from the metamorphic influence of this intrusion, its structural effect consisted in crushing the rock ahead, in fracturing it, and in opening fissures. Similarly, a knob or miniature laccolith exposed on the north side of the main road just west of the West Quincy mine reveals flexing of beds, crushing, shattering, and fissuring.

The great intrusive bodies may reasonably be supposed to have acted in precisely the same manner on a proportionately larger scale. Thus, in the area of the Frog Valley overthrust fault and the McHenry and Cottonwood faults, a wedge a mile long north and south and 2,000 feet thick, comprising the lower formations on the west, is thrust up over the Park City and Woodside formations on the east until the Weber quartzite laps against the Thaynes formation; and on the south a block averaging 2 miles in width north and south and made up of sedimentary formations from the Weber to the Thaynes and intruded porphyries has moved bodily eastward at least 2 miles.

The evidence indicates that a series of intrusive bodies extends in a narrow east-west belt across the Wasatch Range; that they invaded the Park City area from the west, breaking upward and eastward; that those in this area are thus the highest and easternmost members; that at the east end and ahead of this chain of intrusives the formations are

thrust eastward, one formation completely over the next two normally overlying ones; and that directly in the path of the intrusives the formations have given way, chiefly on two great faults, and have moved relatively eastward at least 2 miles.

The occurrence of horses of limestone of Pennsylvanian and of lower Mississippian (Madison) age in diorite porphyry in the southeastern portion of this area also indicates extreme deformation by intrusives, blocks of limestone from a few feet up to 1,000 and even 2,000 feet in length being entirely inclosed in porphyry. Some of these blocks may be safely correlated, by their relative position, with certain near-by limestone members intercalated in the Weber quartzite. Fossil evidence, in the opinion of Dr. Girty, shows some to be lower Weber (Pennsylvanian) and others to be Madison (lower Mississippian). In other words, the horses pretty clearly belong lower by several thousand feet than the lowest sediments outcropping in their normal sequence in this region, showing that the intrusive magma tore away portions of lower-lying formations and floated them up for thousands of feet.

HYDROTHERMAL METAMORPHISM.

Alteration by hot waters takes place chiefly along fissures and is characterized by the formation of quartz, sericite, and pyrite, and locally by other minerals. It occurs in the Park City district along certain major zones of fracture, especially adjoining extensive bodies of intrusive rock.

CONTACT METAMORPHISM.

EXTENT AND GENERAL CHARACTER.

The intrusion of diorite and of diorite porphyry has altered the sedimentary rocks for a variable distance—averaging, probably, a good deal less than a mile—from the contact on every side. The contact-metamorphic effects are most conspicuous, and have been most thoroughly studied, along that rugged western segment of the Weber-Provo watershed that is sometimes called the "contact divide." This crest lies near, and in general parallel to, the north side of the Alta-Clayton Peak stock. Its location and its rugged character depend upon the exceptional toughness of the metamorphic rocks that were formed near the diorite from strata whose resistance to erosion is normally weak. In a considerable area extending along the contact divide, the formations are so disguised by induration, change of color, recrystallization, and the development of new minerals that their boundaries can not be traced and they are mapped together. In many places, however, formations or even individual beds may be traced from outcrops where they are unaltered to the very contact, and the effect of metamorphism traced through all its gradations.

ALTERATION OF LIMESTONE.

The limestones have been greatly altered. Limestone has been replaced by sulphides in some places at the immediate contact, and it has been extensively altered to marble and to rocks containing metamorphic silicates.

Perhaps the most perfect example of sulphide along a contact was observed in the Silver King mine, 1,100-foot level, on the south crosscut at the fork of the drift west, where a band of pyrite about half an inch thick lay between diorite porphyry and a calcareous bed in a gangue of calcite. In the Daly West mine also a body of rich sulphide ore in metamorphic limestone immediately overlay diorite porphyry.

Coarse white marble may be seen at many places along the "contact divide" and in the horses of limestone inclosed by the diorite porphyry east of Bonanza Flat. There is little doubt that at all these places, which are near the contact, the recrystallization of the limestone was caused by the intrusive rocks. On the other hand, the marble that occurs on a knob southeast of Frog Valley, about a mile away from any exposed intrusive rock and close to the great Frog Valley overthrust, may have been formed by dynamic metamorphism due to the overthrusting.

The metamorphosed limestone containing silicates is generally greenish gray to olive-green in color. It is most abundant in the Thaynes limestone, which forms a large part of the contact divide, and is well exposed on the crest south of the Daly-Judge mine, on Jupiter Hill, and near Scott Peak.

The minerals developed by this metamorphism comprise most of the regular contact-metamorphic series, the most common probably being epidote. Brown and green garnet are also found, generally in massive form but

here and there partly crystallized. At one point large masses of vesuvianite are intergrown with spinel and minute crystals of chabazite are scattered thickly over the surface of the metamorphosed rock. Augite is abundant in many places. Mica is present, both biotite and muscovite, but chiefly the latter. Plagioclase feldspar, probably albite, was also detected.

In some places these minerals are massive, composing the entire rock, and in others they lie in a matrix of calcite. Associated with them are the metallic minerals specularite, sphalerite, pyrite, chalcopyrite, and magnetite, intergrown with the metamorphic silicates in such a way as to demonstrate their contemporaneous origin.

ALTERATION OF SHALE AND SANDSTONE.

The contact metamorphism of shale is as pronounced as that undergone by limestone, though less varied and perhaps less extensive. Metamorphosed Woodside and Ankareh shales occur south and east of the Daly-Judge shaft, and also in Jupiter Hill. The most conspicuous effect of metamorphism in the shales is the alteration of their prevailing color from red to green. Complete gradations may be traced from unaltered red shale to tough green hornstone, intermediate stages being represented by rocks that are mottled in green and red. Microscopic examination shows that this characteristic alteration is due chiefly to the development of epidote. There also appears to be an increase in quartz.

In the metamorphism of the coarser siliceous rocks, as sandstone, the apparent change is still more simple and less extensive. The impurities of the matrix are driven off and the silica, doubtless with additional magmatic silica, is united with the quartz grains in a solid mass of quartzite.

ORE DEPOSITS.[1]

MINERALOGY OF THE ORES.

NATIVE ELEMENTS.

Gold.—The "gold ledge" in the Silver King mine, 700-foot level, is reported to have yielded considerable gold, but microscopic examination of the rusty material failed to reveal gold. Men who sluiced and washed tailings in Woodside Gulch below the Silver King and old Mayflower mills and also in Silver Creek in Park City proper are reported to have saved gold enough to make good pay.

SULPHIDES.

Galena.—The isometric lead sulphide (PbS) is the principal ore mineral in this district. It commonly occurs in massive form, both cleavable and granular, rarely crystalline, in fissures and beds in limestone and locally in quartzite.

Pyrite.—The only iron sulphide observed in the district, pyrite, is a relatively unimportant constituent of the ores. It is probably most common in ores which occur in or adjacent to fissures. Its usual occurrence is in granular, massive, and semicrystalline form intergrown with other sulphides in lode ores or interbanded with them in lode and replacement ores.

Chalcopyrite.—The sulphide of copper and iron, chalcopyrite, is rarely seen in the Park City district. In the few occurrences observed it is in massive form intimately intergrown with pyrite, galena, or sphalerite.

Chalcocite.—The black sulphide of copper, chalcocite, is rare in the district. It occurs sparingly as a coating on chalcopyrite and on cupriferous pyrite, more commonly in fracture zones at moderate depth. Nowhere is it known to form a vein or solid minable mass.

Sphalerite.—The sulphide of zinc, sphalerite, occurs abundantly in various forms throughout the district, usually in a rather deep brown to resin-colored massive specular form intergrown with ore minerals and in semicrystalline form. It is more common in lodes, particularly at considerable depth, and in beds in the Thaynes formation adjacent to fissures. It appears to increase with nearness to extensive intrusive bodies, as in the great fracture zone in the Ontario, Daly West, and Daly-Judge, and their bed ores adjoining fissures in the Kearns-Keith and California.

SULPHARSENITES AND SULPHANTIMONITES.

Tetrahedrite.—Gray copper, tetrahedrite, is a complex sulphantimonite of copper ($4Cu_2S.Sb_2S_3$), which may contain arsenic and zinc. It occurs widely in this district in lodes and somewhat less commonly in bed ores, in both massive and crystalline form.

[1] Abstracted from Boutwell, J. M., op. cit., pp. 105–130. Descriptions of a few minerals found since Boutwell's study of the district are inserted.

Jamesonite.—Jamesonite was determined in three specimens from the California mine dump. Van Horn[1] states that he has found jamesonite in notable amounts in the district.

Bournonite.—Van Horn reports finding bournonite $(PbCu_2)Sb_2S_3$ at the Silver King and Daly West mines.

CHLORIDES AND FLUORIDES.

Cerargyrite.—A specimen of rich copper ore from the ore bed in the Scottish Chief mine at the third level was reported to carry high values in silver. On chemical examination Dr. Hillebrand detected a chloride which he is inclined to regard as that of silver—cerargyrite. It was not found, however, in sufficient quantity to recognize with the naked eye.

Fluorite.—Fluorite was found in intimate association with lead-silver ore in two mines and was suspected at a few other points.

OXIDES.

Massicot.—One of the principal features of the mineralogy of the ores in this district is the earthy yellowish material resulting from the alteration of lead minerals. It varies from a dusty, bright-yellow coating through dull waxy, rusty and brownish-yellow or flesh-colored solid masses inclosing cores made up of concentric layers of cerusite, anglesite, and galena. In the mixed galena-tetrahedrite ore the products of oxidation of copper are also present. Qualitative analysis of the material shows that it is a mixture of several secondary lead minerals. Most careful attempts to isolate any particular class of this material for analysis were only partly successful, as the analysis indicates the presence of several minerals, probably including the lead monoxide, massicot (PbO); the complex hydrous antimonate of lead, bindheimite; a little of the arsenate of lead, mimetite; probably other lead compounds; limonite; and calcite.

Magnetite.—Magnetite has been found in a number of places in the district but is not common. It occurs with garnet as a contact mineral in limestone adjacent to intrusive rocks.

Specularite.—The micaceous or specular variety of hematite, specularite, occurs at several points as a contact-metamorphic mineral in limestone adjacent to intrusive rocks. It is most abundant in the contact zone at the southern head of Thaynes Canyon and along the overlooking divide to the southwest. The Thaynes formation was here invaded by diorite magma, which apparently extended northward underneath the sediments. Along the zone immediately overlying this intrusive and adjoining the dikes that break upward across the bedding the limestone is highly metamorphosed. The specularite occurs in sheaves, in curved folia, in large irregular masses, and in bands closely associated and intergrown with the products of contact metamorphism of the limestone. Green garnet is most abundant, with much calcite, some greenish quartz, and probably some epidote.

Limonite.—Hydrous oxide of iron, limonite, is found most abundantly in the oxidized superficial parts of ore bodies which have an iron base. Workings in ore zones near the surface have revealed extensive masses of limonite.

Pyrolusite.—A black mineral occurs commonly in the form of a dense black coating and also as a sooty powder on croppings of ore shoots and underground ore zones. An excellent sample taken from the cropping of the Ontario lode was determined by Dr. Hillebrand to be an "oxide of manganese."

Quartz.—Quartz is found in very many forms, both massive and crystalline, throughout the district but is not particularly abundant. In both lodes and beds the massive variety is a common gangue of the ore. In beds it is locally porous and honeycombed, as on some of the upper levels of the Silver King mine and on the Hanauer tunnel level. In lodes a massive gray silica commonly forms the body of the vein, with sugary quartz occupying areas among the metallic constituents. In the ore-bearing fracture zones in Daly-Judge ground on the west geodes formed, in which some excellent quartz crystals were found. One such specimen, which is the property of the Park City Bank, showed single crystals 3 inches across and 5 to 6 inches long. Another from the same locality shows sphalerite crystals embedded in and partly coated by aggregates of small quartz crystals. One of the most perfect crystals seen was found in the dump of the Jupiter lower tunnel. It is 1 by 2½ inches and shows at least four rhombohedra. On the Hanauer tunnel level of the Kearns-Keith mine the ore is locally replaced by layers of quartz a quar-

[1] Van Horn, F. R., Geol. Soc. America Bull., vol. 25, p. 47, 1914.

ter of an inch thick, whose upper and lower surfaces are formed of crystals; these layers, like the walls of the ore body, are parallel to the bedding. The more common associates of the quartz are sphalerite and galena.

Spinel.—In the southwest corner of the area, 2,550 feet S. 35° E. from Clayton Peak, a boulder about 2 feet in diameter was found in talus about at the contact of the main diorite mass with limestone. The limestone along the contact is highly metamorphosed, showing contact minerals, and the boulder is a solid mass entirely made up of two contact minerals—spinel and vesuvianite.

CARBONATES.

Cerusite.—The carbonate of lead occurs commonly throughout the district as a normal product. Its more usual occurrence is in crevices or pits in galena which are lined with a thin zone of anglesite that bears inside a velvet-like layer of minute tabular pinkish to pearly-white crystals of cerusite.

Azurite and malachite.—The comparatively rare occurrence of the primary copper sulphides results naturally in a corresponding dearth of copper carbonates. They are, however, encountered here and there in the zone of superficial alteration and along fractures affording waterways.

Rhodochrosite.—Two possible occurrences of rhodochrosite are known. Part of a gangue mineral determined chemically to be rhodonite gave a slight intumescence, which was probably due to the presence of some of the carbonate rhodochrosite. Again, a specimen of pink semicrystalline material showing aggregates of minute curved rhombohedra is either rhodochrosite or colored dolomite.

Calcite.—A relatively unimportant part is played by calcite among the minerals of the district. It occurs locally as gangue in zinciferous lead ores, usually in bed deposits but here and there in lodes.

Dolomite.—Dolomite has not been recognized as of common occurrence, though in several places it is believed to be present, associated with calcite.

SILICATES.

Chrysocolla.—The hydrous silicate of copper, chrysocolla, is occasionally found. The best example seen occurred with tetrahedrite in the main ore bed of the Scottish Chief mine, on the third level east.

Garnet.—In certain localities garnet is somewhat abundant, notably in the southern part of the district in limestone adjacent to the great diorite intrusion of Clayton Peak. It is most common in dark-green massive replacements of limestone, though some brown and partly crystalline garnets are found.

Vesuvianite.—Vesuvianite was found in the southwestern part of the district, along the southern contact of the intrusive rock of Clayton Peak with limestone; it is here intergrown with spinel.

Epidote.—Epidote in massive form is associated with garnet and specularite in metamorphic limestone adjacent to the Clayton Peak mass of diorite.

Chlorite.—Chlorite occurs in altered limestone adjacent to intrusives at several points on the surface and underground.

Serpentine.—Seams and beds of serpentine occur in decomposed fractured metamorphic limestone on the 1,500-foot level near No. 2 shaft of the Ontario mine.

Rhodonite.—The silicate of manganese, rhodonite, is rare in this district. On the Ontario 1,500-foot level near No. 2 shaft it is associated with quartz in the gangue of a lode carrying galena, pyrite, and sphalerite.

Mica.—Pale bluish-green imperfect crystals of mica, found in association with silicates which formed in contact zones adjacent to intrusive rocks, probably belong to the chlorite group, though some may be muscovite. One or two blackish hexagonal crystals of mica were seen. All the micas appear to lie at or near an igneous contact. The sericitic variety of muscovite is rather abundant as a gangue mineral. It was noted especially in the Daly-Judge and Silver King mines, where it occurs as a white talcy gangue in fissure ore and as a replacement of limestone.

Chabazite.—In the contact zone along the southern margin of the Clayton Peak stock small pearly white crystals of chabazite fleck the metamorphic material.

Calamine.—Calamine is reported by Van Horn [1] from the Quincy mine.

PHOSPHATES.

Pyromorphite.—In certain croppings and upper portions of shoots of the lead ore pyro-

[1] Van Horn, F. R., op. cit., p. 47.

morphite is probably present in small quantities, but it has not been definitely determined.

Phosphate rock.—Phosphate rock occurs in the Park City formation.

ARSENATES.

Mimetite.—Mimetite is a combination of lead arsenate (90.7 per cent) and lead chloride (9.3 per cent) in hexagonal crystals. It is believed to be present in the yellow oxidation products from the galena-tetrahedrite ores.

Bindheimite.—A yellow mineral believed to be in part bindheimite occurs as an alteration product of galena-tetrahedrite ore.

SULPHATES.

Anglesite.—The sulphate of lead, anglesite, occurs widely in moderate quantities in the lower part of the zone of oxidation, in both lode and replacement bodies, as the first product of the alteration of galena.

Chalcanthite.—The common hydrous sulphate of copper, chalcanthite, is rarely met in the mines of the district.

Barite.—Barite was found at a prospect on top of Flagstaff Mountain, where it had apparently incrusted the walls of fissures in quartzite.

Gypsum.—Gypsum was found in massive form on the dump of an old working of the Summit Co. at the head of Thaynes Canyon, where it apparently has been formed by mine waters. In a specimen of ore from the Wabash mine, 600-foot level south, Lindgren noted semicrystalline to fibrous gypsum forming the gangue of a granular zinciferous galena-tetrahedrite ore.

Goslarite.—The hydrous sulphate of zinc, goslarite, was seen in small fibrous tufts in old workings on walls.

OCCURRENCE OF THE ORES.

TYPES OF ORE.

The ores of the Park City district occur as lode deposits and as bed deposits in sedimentary and intrusive country rocks. The two types of deposits are commonly associated throughout the region, though some lodes and veins occur alone. The principal lodes extend northeast through the heart of the district across Ontario, Empire, and Woodside canyons. The chief bed deposits have been found in Empire and Woodside canyons. Deposits of both types also occur on the east and west. Fissures trending northeastward carry lode ores in the intrusives as well as in quartzite and limestone. Bed ores are most extensive and of highest grade in the Park City formation and are less abundant and leaner in the Thaynes formation. Valuable bed ores have been mined to a depth of somewhat more than 900 feet; rich lode ore has been found to depths of 1,500 feet, and good milling ore to 2,000 feet. In general, the deposits appear to be closely associated with fissures or intrusive rocks.

LODE DEPOSITS.

Croppings.—Several lodes outcrop in this district, the best example probably being the Ontario, in Ontario Canyon. One of the locators of this great mineralized fracture zone has stated that the cropping consisted of "a little knob sticking out of the ground about 2 inches high," and that this was "the only cropping of the lode which was ever found." At the time of Boutwell's examination that part of the vein had been opened and showed on the surface as a zone of crushed quartzite 2 feet wide between definite parallel fissure walls. This zone had been traced along the surface for about 1,100 feet, and downward for 2,000 feet. At the point of discovery and along the strike the filling had undergone secondary and possibly tertiary silicification. The quartz formed is dull, honeycombed, chalcedonic, milky, and massive. The mineralization is indicated by black, brown, green, and yellow stains. The black and brown are manganese oxide, the green is crystalline and amorphous malachite, and the yellowish stains, which are termed by the prospector "chlorides," are not so readily determined but are probably due to alteration products of galena, such as pyromorphite, the oxide, massicot, and the arsenical antimonate, bindheimite. This discoloration or deposit is a common feature on siliceous croppings. On the strike toward the west at a point just west of the Daly boarding house is a rusty quartzite ledge, which is usually regarded as the cropping of the extension of this lode, and south of that, in the fork of the road, is another ledge of quartzite showing sheeting, which is held to be the apex of the vein at that point. Neither of these outcrops shows any mineralization beyond silicification and some staining with iron.

Several other veins and lodes—for example, the New York lode—show rusting along a fracture zone. Some of the fissures on Crescent Ridge are similarly mineralized and show also copper carbonates.

Character.—The lode deposits of the district are extensive, strong, and valuable. They lie in a few continuous master zones, rather than in a large number of small fissures. They may be characterized as argentiferous lead ores with some zinc and, in certain places, copper. The lead is afforded in the upper portions by the carbonates and oxides and below by the sulphide and some sulphate. The silver appears to lie in the pyrite and galena. Zinc is present as the sulphide. Copper appears as carbonates in the upper levels and to some extent at the intermediate levels, but occurs mainly in the deeper levels in tetrahedrite.

In general the upper parts of these deposits have proved richest, the middle section has been of high grade, and the deeper portions larger but leaner. Exceptions are known, however; thus, in the Silver King mine in several places the grade of the ore in the "gash" veins increased with the depth.

Some continuous seams or solid bands of ore occur between frozen contacts. The greater part of the lodes being worked at the present day, however, consist of disconnected seams and bunches of rich sulphide ore scattered through much waste in the fracture zones. Thus, in some of the small properties and on the 300 and 600 foot levels of the Ontario mine, especially in the footwall of the master lode, the ore lies in thin seams frozen to the walls. In the Silver King mine at the lower levels broad bands or tabular masses of solid sulphide ore were found entirely filling fissures. The other, more common, form of deposit is admirably exhibited in the Ontario mine on the 1,500-foot level, and in the Daly West mine on the 1,400 and 1,500 foot levels, where a strong fracture and breccia zone 100 feet in width is occupied by crushed quartzite which includes seams, streaks, and bunches of sulphide ore.

Intermediate types of occurrence in the Daly West stopes between the 1,400 and 1,500 foot levels consist of single streaks in a wide zone of breccia at or near either wall and a number of roughly parallel pay streaks distributed through the zone. Perhaps the best example of this type of lode deposit was seen at the extreme west end of the Daly West 1,500-foot level, where a lode 35 feet wide is made up of two strong ore streaks on the foot and hanging walls and many narrow seams and lenses of ore in fractures within the lode.

Areal distribution.—The lode deposits lie in a general east-west zone about 3 miles wide, which extends across the central part of the area from the west nearly to its eastern boundary. Some fracturing is found on the north and south, but no noteworthy mineralization except in this particular zone. Within the main Park City zone the master lodes, comprising the great Ontario and Daly West system and the Silver King group, traverse the ground exposed by Ontario, Empire, and Woodside gulches for about 3 miles along their strike and through a width of 2 miles. To the east, in the course of the zone, ore-bearing fissures and lodes have been found in McHenry, Wasatch, Glencoe, and Cottonwood canyons, and to the west of the master lodes, in the same course, other lodes extend across upper Thaynes Canyon. Those on either end, however, are relatively small.

Within this main area of master lodes two subzones are seen. The Ontario and Daly West system lies at the southeast side and includes most of the important lodes. The Silver King subzone lies about a mile to the northwest. Between these two subzones some fissures are found and a few lodes—for example, the American Flag. In general, however, the great lodes lie in two northeast-southwest zones about a mile apart.

Fissure systems.—The grouping of fissures into systems according to their trends, which has proved most significant in certain districts, does not appear to be practicable in the present area. Most of the fractures trend east, and a few transverse fissures trend north. Intersections are extremely rare. Characteristic members of the prevailing system are seen in the Ontario and Daly West fissure zones and the Silver King and Kearns-Keith fissure zones. The principal members of the other system recognized on the surface are the Frog Valley fault and the Massachusetts fault.

Intersections along these strongest members of the lesser system could not be made out. The fairly accordant alignment of the known

portions of the Frog Valley fault and of topographic features athwart the course of the east-west faults marked by Drain Tunnel Gulch and McHenry Canyon suggests that the north-south system is the younger. The Massachusetts fault was not observed, on the surface or underground, in juxtaposition with any other fault.

Underground, in the Silver King, Kearns-Keith, and Daly West mines, members of the main east-west system are in a few places cut by small fissures of the north-south system. This evidence accords with that noted on the surface in tending to show that the latter system is the younger.

Highly characteristic of the greater fissure system in this district is a branching or forking habit. Thus in both the southern series opened through the Ontario, Daly, Daly West, and Daly-Judge mines and the northern series opened through the Woodside, Mayflower, and Silver King mines the fissures of the east-west system appear to divide and subdivide. The feature is best shown in the Ontario mine, where a number of these branches or "spurs" have been extensively developed. Critical examination of their junctions indicates that these spurs are true branches contemporaneous with the parent fissures. They usually diverge slightly and then continue roughly parallel to the original fissure. It is hazardous, however, to conclude unqualifiedly that these "spurs" are not portions of oblique fissures cut by the master fissure, as the physical appearance of the junctions might be similar with either manner of origin. But so far as known no continuations (truncated extensions) have been found in the hanging wall and it is most probable that the "spurs" are true branch fissures.

Lode systems.—The system which trends east-northeast appears to include most of the great lodes The Ontario lode trends N. 60° E. (average); the Daly West lode N. 60° E.; and the Silver King lodes N. 60°–80° E. Most lodes trending differently are branches from lodes of this prevailing trend or closely approach this trend.

Localization in shoots.—Unfortunately large portions of the extensive workings on the veins are inaccessible. Nevertheless, certain fairly well-defined localizations of ore into shoots were recognizable. Thus, stope maps and sections published by the Ontario Co. indicate an extensive strong shoot pitching steeply westward from the surface on either side of Ontario Canyon to the lowest levels. Another of less extent, on the west, was opened through raise 3, and a third in the vicinity of raises 4 and 5. It appeared underground that enlargement of the lode occurred at the junction of the master lode with a few "spur" or branch veins, but intersections or forkings could not be established as the determining cause of the greater shoots. It seems not improbable that their location and form may be governed by that of passageways and inequalities in the original fissure.

In the Daly West similar localizations of ore or enlargements of the lode comprise two major and several minor shoots. One at the west end of the property is about 600 feet in length and is 35 feet in width just above the 1,400-foot level. The second shoot, lying north of the shaft, had been opened on the 1,500-foot level for 300 feet to a width of 30 feet. This shoot is unlike the former, which has bands or pay streaks of good width and tolerable persistence, in that the ores are distributed rather evenly in seams and bunches through a mass of crushed gangue.

The ore of the lodes in Silver King ground was not, so far as could be observed, localized into definite shoots. The nearest approach to one occurred in the "gash" lode near the Donkey winze. This was a lens or wedge-shaped mass of high-grade galena ore 20 feet through at its thickest part and followed 200 feet on its dip. It feathered out upward and laterally and terminated abruptly downward. No good reason for its location was apparent.

In several of the smaller mines—for example, the Scottish Chief and Valeo—small shoots have been opened. When any reason for their formation could be found, it seemed to be either the form of the original fissure, or intersection with a feeding fissure, or shattering and consequent greater permeability of the country rock.

Relation to wall rock.—The influence of wall rock on lode ore, whether as regards position, amount, or character, was not very marked.

Long observation in the Ontario mine has given rise to the saying that the highest-grade silver-lead ore lies between quartzite walls,

whereas ferruginous and zincky material occurs in the porphyry on the lower levels. Limestone walls naturally lend themselves to replacement and are apt to inclose the widest and most irregular lodes of the replacement type. For this reason, probably, veins were observed to expand between calcareous walls and to contract on reaching more siliceous or quartzitic walls.

The physical character of the wall rock seems to have influenced the character of fissures in a number of places. Thus, in the Ontario the massive quartzite seems to favor strong, even, well-defined fractures; limestone apparently breaks under stresses less readily and evenly; and porphyry contains the most irregular and ill-defined fractures.

Persistency.—In general, the fractures are strong, well defined, and notably persistent. The best example is found in the Ontario-Daly West system. The main Ontario fissure has been explored continuously along its strike for approximately 5,000 feet, and the Daly-Daly West fissure, in the footwall of the Ontario and beyond to the west, for approximately 5,000 feet. Within these fissure zones the Ontario lode has been mined for about 4,000 feet, and thence along spur 2, a great lode, comprising the Daly and Daly West veins, has been mined for 5,000 feet more. The Ontario fissure is said to end on the east abruptly against a transverse fault. Its western end (in 1912) was a strong zone of sharp, well-defined fissures and brecciation that gave every indication of continuance. The ore within this fracture zone, however, pinched out nearly a thousand feet back to the east by normal feathering out, and the long stretch of comparatively barren fracture zone discouraged further work. However, another shoot may be found farther to the west. Similarly, the great Daly West lode, where opened in Daly-Judge ground west of that shaft, showed a strong fracture zone, and reports of latest developments indicate good ore contents.

The fracture zones containing the strongest lodes in Silver King ground, the "gash" and the "gold ledge," appear to continue with good strength beyond the extreme points opened. But the ore in them pinched out, and, owing to the barren unmineralized aspect of the fracture zones beyond, exploration was not carried further, though the continuations of the zones may contain ore. Smaller lodes show similar features.

The persistence of fissures in depth has been well said to be approximately proportional to their extent along their strike—that is, the longer and stronger the fissure the greater the depth to which it may be expected to extend. The fissures and fracture zones of this district are no exceptions to this broad generalization. Thus, the long Ontario zone has been opened continuously from the surface to the 2,000-foot level and is wider, stronger, and more sharply defined on the 1,700-foot level than at the surface. On the bottom, or 2,000-foot level, it lies largely in porphyry, where it is naturally less distinct, but even at this depth it shows great strength, excellent walls, and widths of 1 to 2 feet. The mineral contents vary considerably, being greatest and richest between the 500 and 800 foot levels, especially between the 600 and 750 foot levels, and good down to the 1,500-foot level, where the width rose to 100 feet and the ore became a low-grade milling ore. Below this level between limestone walls, and particularly on the lowest level in porphyry, the ore was of low grade and carried much iron and zinc. This zincky ore on the bottom level occurred in two shoots—one east of the shaft and the other west.

To the west the Daly West lode at a depth of 1,500 feet appeared like the Ontario lode at the 1,500-foot level—a notably wide zone of low-grade or milling ore carrying considerable iron and zinc in a gangue of silica. Development at lower levels is said to reveal the continuation downward of similar features.

The fractures of the "gash" lode in Silver King ground seemed to extend downward in the form of a broad zone of sheeting. The main shoot in this zone was reported by the operators to have terminated below sharply at a depth of 1,100 feet along a regular plane.

In some of the lesser mines shoots have been bottomed and in others found to persist to the deepest point worked.

In brief, it appears that although certain shoots of high-grade ore have given out at depths of approximately 1,000 to 1,500 feet, the fracture zones persist with great strength beyond the greatest depths explored, some carrying bunches of high-grade ore and others only large masses of milling ore.

BED DEPOSITS.

Croppings.—Two great series of bed deposits have been opened—that in Silver King ground and that in Daly West ground—and a number of minor deposits, including those in the Daly-Judge, Kearns-Keith, and Comstock mines. Certain outcrops have been held to be apexes of known ore bodies below, and underground work in connection with ownership litigation was asserted to have established continuous connection between ore bodies and croppings. It is unfortunate that the areas in which the beds that include the large, rich ore bodies would normally outcrop are deeply buried beneath glacial deposits. The known distinct cropping of the great Mayflower ore body led to an ore shoot which descended gradually into Silver King ground and might naturally be taken for a bed deposit. Although its inclination was doubtless influenced by the limestone beds, the parts of the shoot observed by the writer tend to show that its position and course are closely connected with fissures and that it can not be regarded as a normal bed deposit. Its cropping is said to have been a mass of solid galena. North of the mouth of Walker and Webster Gulch, about 400 feet directly above the Daly-Judge mill, a fracture zone contours the slope and at certain points marks the surface contact between the Weber quartzite and the Park City formation. Parts of this zone, which has been mined out, are said to have been mineralized. In the noted Fairview suit this was claimed as the apex of certain Silver King ore bodies, and an attempt was made to demonstrate this by making a connection.

The outcrop of the great ore-bearing bed in the Daly West ground and the croppings of shoots in this bed were not detected. The connection of the Daly West ore bed upward in the Quincy and Little Bell has been a mooted point, and its positive demonstration is rendered most difficult by complications due to intrusion and faulting. The cropping of the Quincy ore-bearing bed, the equivalent of the Daly West bed, is said to have been found at the east end of the present mine and just below the present wagon road. A connection between this cropping and the 100-foot level is stated to have followed the main shoot from the surface to the great ore bodies underground, but examination failed to reveal ore either in the raise or in the croppings. About the headward slopes of the canyon the extensive intrusive mass of porphyry occupies the area in which the contact between Weber quartzite and Park City formation and the contact with the overlying ore-bearing member would normally outcrop. Again, a fault which traverses the bottom of the canyon just east of the Little Bell shaft may have dropped the ore-bearing member, so preventing its outcrop. The cropping of that member was not observed in mapping this region. Thus, in neither the Silver King nor the Daly West area were actual croppings of known bed-ore bodies observed.

On the southern slope of Scott Hill, however, on the Scottish Chief property, there are apparently croppings of a true bed ore body. Galena, anglesite, and cerusite occur here, with a gangue of calcite, garnet, and limonite, in a bed of coarse marble which belongs to the Thaynes formation. This ore-bearing bed has been followed underground and a shoot developed which appears to be the downward extension from these croppings.

Character.—The bed deposits form the bonanzas of this district. Many of them are large, continuous, of high grade, and comparatively shallow. The profits from these deposits have placed the younger large properties, such as the Daly West and Quincy and Silver King, among the great producing and dividend-paying mines.

In general the bed ores are sulphides, with some oxides of smelting grade. Those from the deeper or isolated parts of the beds are mainly galena, some gray copper, and pyrite. In certain places considerable sphalerite is present. The galena is both coarse and fine cleavable. In the oxidized portions anglesite, cerusite, an antimonate (probably bindheimite), and malachite are found. Calcite and quartz form the prevailing gangue. The ores are commonly dense and heavy, only the highly oxidized portions being lighter in weight, semiporous, and powdery.

Areal distribution.—The valuable bed deposits have been found on the upper north side of the main eastern spur from the Wasatch Range, which forms the main divide of the district. They thus lie about the headward portions of Empire, Woodside, and Thaynes canyons in the Daly West, Quincy, Daly-Judge, Silver King, Comstock, and Scottish

Chief mines. Excellent bed ore is also found in Walker and Webster Gulch and is developed in the Kearns-Keith mine. Aside from these, only minor bed deposits were observed.

Geologic distribution.—The bed ores occur in sedimentary formations that adjoin the northern flank of the great Clayton Peak laccolith of diorite and dip north and west over Weber quartzite. The ore bodies are found in the calcareous sediments. The Park City and Thaynes formations contain the bonanza ore. The Weber quartzite is known to carry a few small and isolated beds of no commercial importance. The two red-shale formations, the Woodside and Ankareh, are not known to be ore bearing. In the two calcareous formations the siliceous members are commonly barren. Much the larger number of bodies and much the higher grade of ore has been found in the Park City formation, which contained the extensive bodies of rich bed ore mined from Silver King and Daly West ground and some from the Daly-Judge. In the Thaynes formation, however, were found some of the bed bodies in the Daly-Judge, Kearns-Keith, Comstock, California, and Scottish Chief mines.

The character of the ores from the two formations is most distinct. Those from the Thaynes formation are commonly high in sphalerite, iron, and silica and are not only much lower in grade but much less desirable for either smelting or milling than those from the Park City formation. As compensation, however, they afford the zinc product which in recent years has been turned to excellent commercial advantage.

It appears further that bed ore is practically restricted not only to these two formations but to certain members of them. This restriction is more notably true of the Park City formation. In the Daly West mine, on the 900-foot level, in the south crosscut at the west end of the property the bed deposits occur mostly in a certain limestone member 4 to 6 feet thick that lies approximately 60 feet above the Weber quartzite, between a hanging wall of fine siliceous gray impure limestone and a footwall of brown sandy quartzite. This favorable stratum is underlain successively by the following beds:

Section of beds below ore-bearing member in Daly West mine, 900-foot level.

	Feet.
Cherty massive brown sandstone	12-15
Light-gray limestone, black cherts at top	4-5
Black limestone, carbonaceous at base	20
White sandstone	7
Gray siliceous limestone with sandy beds	15
Thin-banded gray shaly limestone	1½
Weber quartzite.	

Similarly in the Silver King mine the principal bed deposits occur in a limestone member in the lower part of the Park City formation. Along the crosscut running northeast from the station on the 900-foot level the drift passes up through the Weber quartzite and the basal part of the Park City formation to the ore-bearing member. The beds traversed clearly embrace the equivalents of those noted in the Daly West, and other beds that were not observed in that mine. The existence of many strong strike faults renders any close measurement of thickness impossible. In general it appears here and elsewhere through this property that the principal ore-bearing member is somewhat higher than to the southeast in Daly West ground, being approximately 100 feet above the Weber quartzite, as shown in the structure section through the Silver King shaft and ore-bearing member. The ore-bearing series here comprises a bed of fine even-grained gray siliceous limestone overlying a fine-grained grayish brown quartzite. The ore appears to have formed in the base of the limestone over the quartzite. Above, on the 800-foot level, where the ore bed and walls show more clearly, a 3-foot bed of shaly limestone that gives way to ore lies between walls of fine-grained gray siliceous limestone.

Variations from these normal conditions were also noted. In the Silver King mine certain beds at horizons above the main deposit carry ore in places. In the Daly West mine above drift C a large stope shows double ore beds, where a layer of brown sandstone or quartzite known as the "parting quartzite" separates a 15-foot bed of ore from an underlying 6-foot bed of ore. Again, on the '01 level west, ore occurred in limestone immediately overlying Weber quartzite.

In order to ascertain the determining factors in the selective action through which ore forms

in certain beds to the exclusion of others, samples were taken from the beds in which the ore is best and from the hanging wall and footwall of those beds. The samples from the Silver King and Daly West mines are from the Park City formation and those from the Scottish Chief are from the Thaynes formation. Partial analyses follows:

Analyses of rock from ore beds and walls.

[Analyst, George Steiger, United States Geological Survey.]

	1	2	3	4	5	6	7	8	9
SiO_2	1.50	4.54	86.77	2.97	3.81	64.86	1.90	63.81	70.05
Al_2O_3	.31	.64	2.81	.68	.19	1.36	1.70	9.67	7.47
Fe_2O_3	.11	None.	.40	None.	.38	.46	1.62	None.	.19
FeO	.16	.30	.16	.32	.16	.13	1.40	2.17	1.17
MgO	20.41	19.07	.92	19.11	19.54	6.30	1.04	4.30	2.81
CaO	30.54	29.69	3.99	28.04	30.11	10.60	50.51	11.98	11.84
TiO_2	None.	.04	.12	None.	....	.08	.08	.67	.52
CO_2	46.03	44.27	3.44	44.00	44.78	13.78	39.66	1.11	1.03
MnO	.28	.25	.02	.57	....	.19	.70	.44	.31

1. Bed replaced by main bedded ore deposits, Silver King mine, stope on 700-foot level west (specimen 1126).
2. Hanging wall immediately over main ore bed, Silver King mine, stope on 700-foot level west (specimen 1128).
3. Second true hanging-wall bed, Silver King mine, stope on 700-foot level west (specimen 1130).
4. Footwall immediately under main ore bed, Silver King mine, stope on 700-foot level west (specimen 1131).
5. Bed replaced by main ore bed, Daly West mine, stope A (specimen 953).
6. "Parting quartzite," barren bed between two ore beds, Daly West mine, roll incline between B and C levels (specimen 957).
7. Bed replaced by main ore bed, Scottish Chief mine (specimen 974).
8. Hanging wall of main ore bed, Scottish Chief mine (specimen 975).
9. Footwall of main ore bed, Scottish Chief mine (specimen 973).

The figures showing the composition of these beds bring out certain broad facts clearly. The ore beds are low in silica and high in lime, and those from the Park City formation are highly magnesian. The hanging walls, on the other hand, are high in silica and relatively low in lime, except No. 2, which was probably part of the ore bed and barren at the point of collection, the true hanging wall being No. 3. The footwalls are also high in silica and low in lime, except No. 4, which is likewise doubtless a barren portion of the ore bed instead of the true footwall. The specimens from the Scottish Chief show most clearly the high lime and low silica content of the ore bed and high silica and low lime of the walls. In brief, it appears that the ore forms best in pure or magnesian limestone and that the walls are siliceous.

Form and structure.—In general, the bed deposits are roughly lenticular. Some are very long along the strike, but most are longest along the dip. The margins are as a rule irregularly lobed, some of the lobes or arms being of considerable length. The periphery is commonly attenuated until it disappears. Normally these deposits occur in single or simple lenses, but some of them become compounded through the duplication of the original by others above and below.

The dimensions of the lenses differ greatly. The thickness ranges from a few inches to 6 or even 10 feet. The maximum dimension is usually the length along the strike, which in some lenses is approximately 500 feet and in one or two is indicated by mine maps as 600 to 800 feet. The width in the direction of dip averages possibly 50 feet, reaching 100 feet in several lenses, 150 feet in the great stope at the west end of the Daly West property on the 900-foot level, and about 200 feet through a length of 600 feet in the great stope in the Silver King mine.

As the lenses of ore coincide with or occupy parts of beds of limestone the dip and strike of these bedded deposits agree roughly with those of the inclosing limestone members. In some places entire members or beds of the limestone give way to ore. Many such beds of ore end evenly above and below on bedding planes of the overlying and underlying beds of limestone. Probably more of them, however, extend irregularly upward across the bedding, some ending in tongues or bulging surfaces and others expanding at a higher horizon to form a second ore bed.

Each bed of ore is made up of layers or laminae that correspond to the laminae of limestone which make up the member or bed of limestone. These layers range from a small fraction of an

inch up to 1 or 2 inches in thickness, according to the thickness of the bands forming the original limestone bed. Finally, these laminae are seen, some by the naked eye and others by the microscope, to be themselves built up of minute layers of ore, which under the microscope are seen to be composed of interlocking grains of the several ore and gangue minerals, on a pattern similar to that of the original limestone. In the great stope A of the Daly West mine the upper face showed, between evenly preserved bedding planes, a 6-foot bed of banded ore that was made up as follows:

Section of ore bed in stope A, Daly West mine.

	Inches.
Coarse galena, with sphalerite	8-10
Fine-grained siliceous limestone	6
Pyrite, galena, and gray copper in siliceous limestone.	8
Coarse galena with white quartz	6
Massive fine-grained galena and gray copper	18
Slightly oxidized ore with quartz bands	12
Footwall sandstone.	

Similarly, on the 900-foot level at the west end the upper face shows a 4-foot bed of banded argentiferous lead ore between a calcareous sandstone or siliceous limestone hanging wall and a sandstone footwall. The banding is brought out by partings of siliceous gangue. In the Silver King mine the walls of the stope adjacent to the incline at the north end loading from the 750-foot to the 800-foot level show a 4-foot bed of well-banded rich, partly oxidized lead-silver ore between members of the Park City formation. Inspection shows that the bands of ore are structurally continuous with the bands of limestone of the inclosing beds.

In brief, the bed deposits occur in bodies of roughly lenticular form having a banded structure which is conformable with the bedding of the inclosing limestone even down to the minute laminations.

Relation to fissures.—The relation between bed deposits and fissures is intimate and complex. Fissures act both as conduits and as faults. Some of the most important bed deposits have strong, somewhat mineralized fissures rising through their footwalls or descending rootlike from them. Many such mineralized fissures pass upward through siliceous rock to bed deposits in limestone members. Their part as "feeders" is most admirably illustrated on a small scale in the Daly West mine, where an east-west fissure dipping 75° S. and carrying granular carbonate ore crosses limestone beds into certain of which ore extends outward and upward.

In a precisely similar manner, on a larger scale, the mineral-stained though lean fractures in the 900-foot level followed by the back or work drift connecting the ore chutes on the south side ascend to the great bed deposits of the 900-foot level. Similarly, also, east-west, N. 70° W. and N. 80° E. fissures on the 900-foot level have been worked upward for 300 feet into extensive bedded deposits. In the Silver King mine fractures very clearly served as conduits for the solutions which supplied the great flat bed deposit adjacent to the Gillis raise.

The same fractures that served for the passage upward of ore-bearing solutions also served (if they extended to the surface) as conduits for the downward movement of surface waters, thus facilitating the superficial alteration and enrichment of the bedded ore bodies.

Relation to intrusive rocks.—That intrusions played a controlling part in the formation of the ore deposits is evident, but the physical relations between intrusive rocks and bed deposits are not so apparent in this district as elsewhere. Intrusive rocks, although abundant, are not common in close proximity to the great bed deposits. The principal occurrences may be briefly examined.

A great stock of diorite extends into the district from the southwest to the gap above the Daly-Judge and disappears beneath the glacial blanket covering the bottom of Bonanza Flat, and an extensive series of diorite porphyries rising from beneath the glacial blanket continues northeastward across the area, giving way at the extreme northeast to great flows of andesite. Abutting against these intrusive rocks and traversed by minor offshoots from them are the metamorphosed limestone formations in which the bed deposits occur. In the immediate vicinity of these deposits several intrusive masses outcrop. About the head of Empire Canyon, forming the upper part of the Quincy and Little Bell spur, is an extensive mass of diorite porphyry. Dikes of the same rock appear about 125 feet south of the Quincy shaft, about the same distance west of the Daly West shaft, and farther west, extending from the pond southward nearly to the Daly-Judge shaft. Diorite extends through the gap above the Daly-Judge and along the west side of the canyon. At the collar of the old Massachu-

setts shaft a small body of diorite porphyry crops out.

Within the Silver King area, singularly enough, not an outcrop of igneous rock was observed, although the dump at the mouth of a long tunnel up Woodside Gulch above the Silver King office shows much coarse diorite porphyry. Underground also, the immediate vicinity of the great bed deposits of the Silver King mine is singularly free from igneous rocks. A small body of peridotite on the 300-foot level northeast of the shaft, a small sill of the basic porphyry on the 750-foot level, and a block of diorite porphyry on the 800-foot level are all the intrusive rocks known in the heart of the productive portion of the Silver King ground. In outlying portions, however, extensive dikes of coarse diorite porphyry appear.

In the adjacent Kearns-Keith ground bed deposits are in immediate contact with extensive dikes of diorite porphyry.

In the Daly-Judge mine porphyry traverses ground in the vicinity of bed deposits. The most notable example is the well-defined dike of diorite porphyry exposed on the 1,200-foot level for approximately 500 feet.

In the Daly West and Quincy mines bodies of coarse diorite porphyry, cut at several levels, appear to belong to a dike 10 to 40 feet wide, which trends east and apparently stands nearly vertical. West of the Quincy shaft bed ore in limestone abuts against the dike at several points, and on the west, in Daly West ground, extensive bodies of rich ore occur either in contact with or adjacent to it. Perhaps the clearest instance of ore in limestone beds adjacent to porphyry was found at a point where the Daly West dike, expanding to a width of at least 50 feet, cuts limestone in which a large body of rich ore formed immediately over the porphyry. The ore, composed of massive galena, gray copper, and the alteration products anglesite, cerusite, malachite, and azurite, occurred in bands continuous with the banding of the inclosing limestone. The limestone is somewhat altered and oxidized, the porphyry is likewise pyritized and oxidized, and both rocks at the contact show crushing, brecciation, silicification, and oxidation. The occurrence appears to be a normal intrusive contact between a diorite porphyry dike and limestone of the Park City formation, sulphide ore being found in the limestone along bedding adjacent to the porphyry and the whole mass being subsequently somewhat crushed and altered.

The facts show a close relation between bedded deposits and intrusive rocks.

Effect of faulting.—The effect of faults on bed deposits depends primarily on their relative position and age. Obviously a fault that does not intersect an ore body can not directly affect it, and a fracture that crosses an ore body but is of earlier date can have no effect as a fault, although the fissure formed by it may have served, as explained in a previous section, as a conduit for ore-bearing solutions. Faults intersect bed ore bodies and those of later date displace them.

In the Park City district faulting occurred previous to intrusion, and subsequent to intrusion and mineralization it was repeated along the same lines and also occurred along transverse courses. No extensive displacement of ore beds has occurred, indicating that the greater part of the movement on the faults took place before the deposition of the bed ores.

At the Daly West fracture zone the main ore-bearing bed was apparently truncated and displaced along the "roll" fault. The bed ore is clearly bent or dragged up on the north, and fragments of ore that show crushing, rounding, and slickensiding lie in the fissure. Clearly, faulting took place after ore deposition and displaced the bed. The fault strikes east and, where this displacement was noted, it dips 54°-70° S. It is offset to the north at least 40 feet and probably nearer 50 feet. In the stopes on this bed above to the south numerous small postmineral faults may be seen. The footwall shows many small displacements ranging from a few inches up to several feet, with corresponding offsets in the hanging wall. On the upper levels considerable faults of postmineral date have been revealed. In the same manner the ore bed in the Quincy ground is displaced for a few feet at several points.

In the Silver King mine the locus of the great bed deposits is similarly faulted on east-west zones. None of the faults here is more important than the "gash" fracture, whose relation to the bed ore is shown by the development. The "gash" strikes N. 60°-70° E. and dips 60° NW. across the bedded ore body in limestone, which dips at an average 21° N. 55° W. The bed ore and the overlying and underlying beds of limestone end against the "gash" fault,

whose hanging wall here is calcareous sandstone and gray carbonaceous limestone, although at lower levels both its walls are quartzite. The bedded ore is clearly faulted. On the 900-foot level the drag in both footwall and hanging wall indicates a relative displacement downward on the hanging-wall side. Below, just above the 1,000-foot level, a drag on some ore in the footwall suggested movement in the opposite direction. On the whole the probabilities incline toward a drop on the hanging-wall side.

The north-south and related northwest-southeast faults are of still later date and should displace bed ore along intersections. Several such displacements along north-south faults occur in the Silver King and Daly West and in lesser mines, but the offsets appear too small to interfere with mining.

SUPERFICIAL ALTERATION OF ORES.

Alteration of the primary ores by surface waters in the Park City district reaches to a maximum depth of 1,700 feet, and to an average depth of 600 to 700 feet. The principal feature of interest is the complete oxidation of galena-tetrahedrite ores to hydrous antimonate of lead (bindheimite) at a depth of 1,200 feet.

GROUND-WATER LEVEL.

Ground water was encountered near the surface in the early days, but through mining operations it has been lowered to about 1,500 feet in the deepest workings.

EXTENT AND CHARACTER OF ALTERATION.

The bed ores, best exemplified in the Silver King and Daly West mines, are normally oxidized to depths of 500 to 800 feet. Thus the Quincy bed ore was thoroughly oxidized to just above the 300-foot level, where sulphides began, partly oxidized to the 400-foot level, and oxidized in some degree to a depth of 570 feet. In the Daly West, stopes at 630 feet showed cores of sulphide inclosed in carbonate and oxide ore. Lower beds were entirely sulphide. In the Silver King mine the bed ore at the 750 and 800 foot levels was essentially carbonate, though some sulphide was admixed. On the 1,000-foot level, where the "gash" and bed ore bodies come together, the bed ore was entirely sulphide. On the 1,200-foot level west, along a fissure, a bed of ore was completely oxidized.

Alteration varies most along fissures. The Ontario lode, being opened from the surface to a depth of 2,000 feet, affords an excellent scale, though unfortunately much of the upper older portion of the mine is inaccessible. Some of the croppings of the lode showed galena, and on the Union 100-foot level west considerable seams of galena were observed. The outer parts of "spur" veins on the 1,000-foot level were composed of carbonate ore, and some carbonate ore was seen on the 1,700-foot level. In general, however, the oxidized ores were richest between the 600 and 750 foot levels and the carbonate ore below was leaner and less abundant. On the 1,500-foot level the ore was essentially sulphide.

The rich bedded ore in the Silver King and great blocks of slightly altered galena ore from the "gash" at a depth of about 1,100 feet afford complete epitomes of the succession of changes. The primary lead ore (lead sulphide, galena) alters to anglesite and this to cerusite. Further alteration results in a brownish-yellow, waxy amorphous mineral, which eventually passes into a dusty bright-yellow mixture of lead oxide, probably massicot, and several complex inseparable alteration products. Chief among these is a compound of lead and antimony, probably bindheimite, which is apparently derived from both galena and gray copper. Copper first becomes significant with the appearance of tetrahedrite, though some of it is contained in the pyrite. Critical search failed to reveal evidence of secondary origin for this rich copper mineral and thus tended to show that the tetrahedrite is primary and contemporaneous with the intergrown galena. Partly altered specimens of this ore from the Silver King and Daly West mines show pits and cavities crusted with the alteration products of these sulphides. Coating cores of the sulphide are the blue and green carbonates, azurite and malachite.

Silver was not found in sulphide form nor was it recognized in oxidized products. It is known to occur in the galena and in pyrite and sphalerite. Gold was not observed, though proved present by assays. The ore was richest where manganese was abundant, and apparently the gold ran highest where the ore was most altered and decomposed.

GENESIS OF THE ORES.

The rich lode and bed ore bodies that have been successfully exploited are characteristic of their respective types. Broadly, they lie in sedimentary rocks within a few hundred feet of dioritic intrusives and give out within a comparatively short distance from them on either side. At greater distances all the geologic conditions continue the same, except that intrusive rocks are absent. The limit of influence of the intrusive rocks is the limit of workable ore; clearly it is a justifiable general conclusion that the intrusives were requisite for the formation of the ores.

This conclusion is fully supported by closer study of details. Along the zone of intrusives the sediments have suffered contact metamorphism, by which certain minerals—garnet, epidote, vesuvianite, augite, and mica, in a gangue of calcite—were formed that are universally recognized as due to the influence of intrusives. Along the contact, and intergrown with the contact minerals in a manner which clearly proves that they were formed at the same time, are the ore minerals pyrite, chalcopyrite, galena, specularite, sphalerite, and magnetite, demonstrating that the bonanza bed ores in limestone were formed by the intrusives.

The formations adjoining the intrusive rocks are much crushed, fractured, and fissured. In certain of these fissure systems, between walls of each type of rock—quartzite, porphyry, and limestone—valuable ores were formed of about the same metallic minerals that compose the bed ores—pyrite, chalcopyrite, galena, and tetrahedrite, with a gangue of quartz, calcite, and sphalerite. Their likeness in mineralogic composition to the bed deposits and their close association with intrusives, whose direct connection with bed deposits has been observed, strongly suggest that intrusives were also the causal factors in their formation. The excess of quartz and pyrite in the gangue and the silicification and sericitization of the walls point to the action of hot, probably alkaline aqueous solutions, such as would be expected to arise from an igneous magma. Finally, the presence of the additional gangue minerals rhodonite and fluorite indicates deposition from hot solutions or vapors expelled by underlying magmas.

Two other facts corroborate the conclusions above stated. The extension of ore in fissures through a composite footwall up to a bed deposit without continuing beyond through the hanging wall, and the definite upward termination of at least one lode, show that the ore-transporting agents moved upward. The inclusion of certain isolated portions of one vein within another, as, for example, the fragments of rhodochrosite and rhodonite as a core in quartz in a vein in Ontario ground, strongly suggests that at least some of the transporting agents were liquid; and consideration of chemical composition, solubility, and temperature leads to the conclusion that they were aqueous.

The process of deposition was one of replacement of limestone beds and, in many places, of the walls of fissures and to a minor extent of fissure fillings. Thus it has been shown that the bed deposits occupy portions of beds of limestone, that the layers or laminae which make up a bed of ore correspond in every way to laminae of limestone which compose the limestone bed, and finally that these laminae are made up of grains of ore and gangue minerals arranged in a pattern resembling that of the original limestone. Lode ores show similar evidence of replacement of walls, and here and there comb structure indicates some filling.

It is clear that ore deposition occurred at two or more periods, which may be dated with reference to other geologic events. Some of the bed ore was deposited contemporaneously with intrusion, but the lode deposits and apparently some of the bed deposits were probably formed later, after at least the surface of the intrusives had cooled to partial rigidity. It has been shown that the diorite is not earlier than Triassic and that the porphyry is at least as late as Lower Triassic and, together with the ore-bearing fissures, is earlier than the "Vermilion Creek" (Eocene). Hence some of the ore deposits were probably formed after Lower Triassic and before "Vermilion Creek" time.

Thus, between early Triassic and early Tertiary time, dioritic intrusives invaded this area, metamorphosed the sediments, and induced the deposition of rich lead-silver ores in certain members of the calcareous formations. After these intrusives had cooled to at least partial rigidity the composite country rock was broken

by persistent northeast fractures. From the deep-lying, still molten remnant of the magma hot gases and aqueous alkaline solutions were expelled, by way of the fissures, upward and outward, transporting ore-making elements to zones where temperature and pressure were low enough to permit the deposition of ores. The hot solutions corroded and replaced with ore some of the purer beds of limestone through which they passed and thus formed the bed deposits. They formed the lode deposits partly by filling the fissures and partly by replacing the walls of fissures. Movement along the northeast fissures brecciated and faulted the ore and was followed by northwest fracturing, along which waters descending from the surface altered the superficial portions of the primary sulphide ores to rich oxide and carbonate ores—a process still in progress.

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BLUE LEDGE DISTRICT.

By V. C. HEIKES.

The Blue Ledge district, in Wasatch County, 5 miles west of Heber on the Denver & Rio Grande Railroad, was organized May 10, 1870. To the end of 1912 approximately 167 patents for mineral ground had been issued. Lead, silver, and gold are the recoverable metals, the output of which has been included in the total output of the Park City district. Huntley[1] gives the early history as follows:

> The Blue Ledge district [had] at the time of the writer's visit (October, 1880), 694 locations on record, of which probably not over 300 are still held. * * * Little ore was being extracted. * * * The McHenry mine was one of the first claims located in the district. The old McHenry Mining Co. was organized in 1873, and built a 20-stamp mill at Park City. The mill ran on company's ore for two months, but the ore was not free milling. The mill was then leased to the Ontario company for about a year. In 1876 the entire property was sold to the Winnamuck company, which expended considerable money in prospecting. The mine was bonded to Chambers, Hanauer & McIntosh for $140,000, who, in 1878-79, spent $20,000 in prospecting it. About December 1, 1880, the Winnamuck company again took possession.

Although ore is said to have been opened on several claims in the district, only the Valeo and Glencoe have had important productions. The Valeo was discovered about 1891. Its history is reviewed by Boutwell,[2] as follows:

[1] Precious metals: Tenth Census U. S., vol. 13, p. 443, 1885.

[2] Geology and ore deposits of the Park City district, Utah: U. S. Geol. Survey Prof. Paper 77, pp. 196-197, 1912.

The Valeo mine is situated on the southeastern slope of Bald Mountain near the head of Cottonwood Canyon, about 4 miles southeast of the Ontario mine and 3 miles south of the Hawkeye-McHenry. This is the principal property on the eastern slope. * * * In 1896 excellent ore was found on this property, and in August of that year some of the ore was shipped and surface improvements were made. * * * The year closed with new ore developments of much value. * * * In the fall of 1898 the property, comprising some 16 claims, was taken over by prominent mine owners to be opened systematically and operated on a large scale. After working out the main ore body they did some development work, but the results were deemed insufficient to warrant much outlay at that time. Since then only desultory work has been carried on, and at the time of visit, late in 1904, the property was inactive.

The metallic contents of the ore reported during the period of active mining were high. Thus, from a new vein cut in 1896, 29 per cent of copper, 10 to 14 ounces of silver, and $6 to $8 in gold to the ton were obtained, and a little later practically these same figures were given as the average tenor of the ore.

The production of copper ore from the Valeo continued intermittently till 1909.

Boutwell[1] has also described the Glencoe property, in part, as follows:

The Glencoe mine is situated on the east slope of Bald Mountain, in Glencoe Canyon, about midway in its length, and near the center of the large intrusive of diorite porphyry that crosses the canyon at this place.

This property was located in the early seventies by Messrs. Cook, McCune, Cupit, and Braun. * * * The property then passed into the hands of the Glencoe Mining Co. * * * Near the close of 1882 the main tunnel had been cut 450 feet on the vein, from which ore had been taken to the amount of 200 or 300 tons. This ore is said to have assayed 40 to 50 per cent of lead and 40 ounces to the ton in silver. During the succeeding year several hundred tons of ore, said to be of low grade and refractory, were stored on the dump. For the following five years, ending with 1888, there is a blank in the record, but during the period from 1889 to 1892 the mine reached its highest prominence. In the first year of this period it was taken over by a new company, having a capital of $2,500,000. Ore continued to be plenty, some new strikes were reported, and the new management decided to erect a concentrator of 100 tons capacity. This was completed in 1891, and was the third concentrator in the camp. The reduction was 4 tons to 1, and the concentrates are reported to have assayed 25 ounces to the ton in silver, 50 per cent of lead, and $3 to the ton in gold. * * * Some carloads of the concentrates were shipped, but the ore grew zincky, and in 1892 the concentrator was hindered somewhat for lack of water. This was the close of the period of prosperity. In 1892 the mine stood idle, and the machinery was attached and sold by the marshal to pay indebtedness thereon of over $11,050. In 1895 the machinery was removed to Bingham, Utah, and meanwhile the completion of the Ontario drain tunnel had largely depleted this property of the water used for milling. In the later nineties and early part of the decade following the mine stood practically idle. * * * In 1904, however, it was leased under bond, and work was resumed, the mill being renovated to treat the ore on the spot. These operations were interrupted by the death of the principal party, and for the next few years the mine is understood to have remained closed. This property was taken over by the Adirondack Mining Co., in 1908, a 150-ton mill was erected at the mine, and other preparations were made for active operation.

[1] Idem, p. 199.

The mill erected for the reduction of Glencoe ores operated for only a short season in 1909, producing lead concentrates containing gold and silver. Nothing has been reported since.

UINTA DISTRICT.

The Uinta district is situated on the eastern slope of the Wasatch Range in Summit County. It was originally a part of the Mountain Lake district, organized in 1867, and was made a separate district on November 18, 1869, being the first of the five districts set off from the Mountain Lake district.[2] It was reorganized July 8, 1871.

The adjoining Snake Creek and Blue Ledge districts were organized in 1870, in April and May, respectively. Parts of these three districts form what is now commonly known as the Park City district.

SNAKE CREEK DISTRICT.

The Snake Creek district, formerly part of the White Pine and Howland district, is in Wasatch County, 10 miles southwest of Heber on the Denver & Rio Grande Railroad. It was organized in 1871. The first locations were the Pioneer and the Idaho, made in the fall of 1871. During 1880[3] the active properties were the Pioneer, Utah, and Jones Bonanza, now owned by the Daly-Judge Mining Co., and the New Bedford.

ELKHORN DISTRICT.

The Elkhorn district is in Wasatch County, east of the Blue Ledge district, or about 4 miles east of the Ontario mine in the Uinta district. Elkhorn district was organized May 21, 1875, and has four patented mining claims and many that are unpatented. The first patented were the Crawford (lot 37) and the

[2] Boutwell, J. M., op. cit., p. 19, 1912.

[3] Huntley, D. B., Precious metals: Tenth Census U. S., vol. 13, p. 443, 1885.

Victory (lot 38). In the discovery shaft of the Nelson and Queen properties samples of ore are said to have assayed 40 per cent lead, 15 ounces of silver, and $5 in gold per ton. Development on this property has reached a depth of about 150 feet.

PROVO DISTRICT.

By G. F. Loughlin.

GENERAL FEATURES.

The Provo district, in the front hills of the Wasatch Range, east of Provo and south of Provo River (Pl. XXXI), was organized March 11, 1871. Considerable prospecting has been carried on, but only the Monarch mine, located in Rock Creek canyon about 1902, has shipped ore. Shipments of only 8 tons of lead-silver ore have been reported to the Survey from the Provo district, but according to a personal letter from Jonathan Buckley, about 50 tons had been shipped from the Monarch mine up to 1913. The property is owned by the Garden City Mining Co.

The Wasatch Range in this region includes the main ridge, known as Provo Peaks, whose summits attain elevations of 10,500 feet and more, and the front hills whose summits reach elevations of 8,500 to 9,000 feet. The front hills are separated from the main ridge by slightly to well developed longitudinal or strike valleys (Pl. XXXII), which are connected by transverse canyons with Utah Valley. The position of the longitudinal valleys, parallel to the Wasatch front, suggests that they are due to faults;[1] but the only structural evidence noted was their coincidence with the outcrops of rapidly weathered strata. The principal transverse canyons, from north to south, are Rock, Dry, and Slate creeks.

The steep west front of the Wasatch Range in this district is fringed by a well-developed portion of the Bonneville shore terrace, and is marked at the mouth of Rock Creek by an exposure of the great Wasatch fault, along which recent movement has taken place. (See Pl. XII, p. 101.)

GEOLOGY.

The sedimentary rocks recognized in the front hills are of pre-Cambrian (?), Cambrian, and Mississippian age. The main ridge consists of upper Mississippian and Pennsylvanian strata, but these lie without the limits of the mining district proper. No igneous rocks have been found in the Wasatch Range east of Provo; the nearest are the granodiorite and quartz diorite stocks in the Cottonwood and American Fork region, 20 miles to the north.

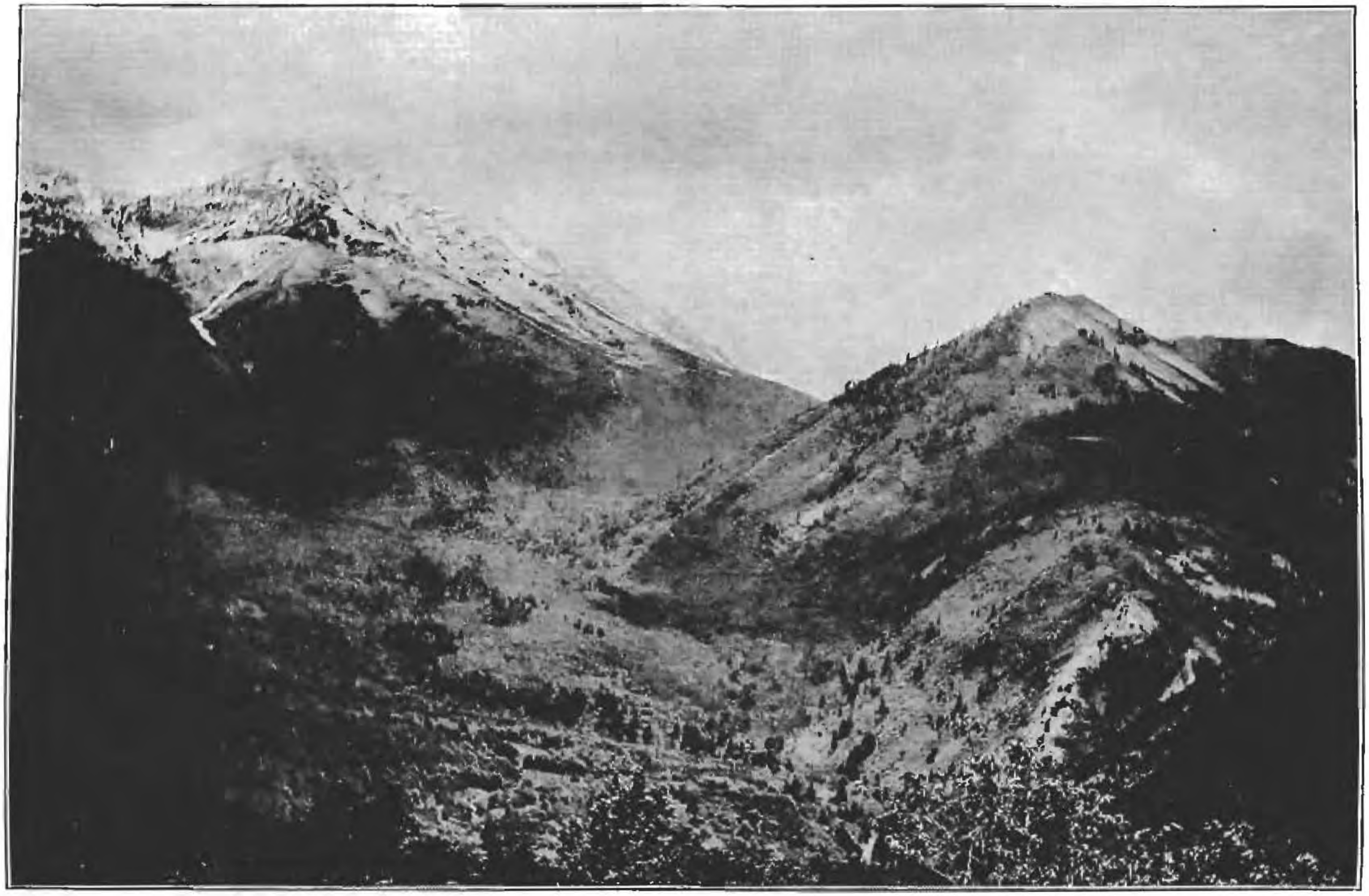
The pre-Cambrian (?) rocks are represented only by a small amount of peculiar conglomerate, similar to that in the Cottonwood and American Fork region to the north. (See p. 234.) It is rather well exposed at the mouth of Rock Creek canyon just above the creek bed, and poorly exposed in the lower part of Slate Creek canyon. It consists of angular to rounded and small to large pebbles of quartzite, schist, vein quartz, and calcareous slate or argillite in dark gray to brown shaly matrix. The Rock Creek exposure is bounded on the west by a fault dipping 60° W., which separates it from mottled shaly limestone, a common variety in the Middle Cambrian of the region. The conglomerate marks approximately the axis of an anticline. At the fault it dips westward at a low angle, but eastward the dip flattens and then changes within a very short distance to vertical.

The Cambrian strata comprise a typical succession of quartzite, shale, and limestone. Two areas of the quartzite are exposed along the steep front slope—one in a gently arching band that pitches northward and southward from Rock Creek, and one in an irregular area that includes another arching band just south of Slate Creek canyon and an eastward-tapering portion along the lower walls of the canyon. West of the quartzite is a light greenish gray rock of medium grain composed of subangular quartz grains enlarged by secondary growth with microscopic interstitial aggregates of chlorite, a few small cubes of pyrite, and some microscopic zircons. In Slate Creek canyon some reddish quartzite beds are present, and in the upper part of the formation several beds of green and purple slate alternate with quartzite. Small amounts of the slate have been quarried in Slate Creek canyon. The quartzite is about 1,500 feet thick and is overlain by about 300 feet of shale (Ophir formation; see p. 79), which is followed by limestone.

The relations of the quartzite and shale to the limestone are conformable. At first sight the vertical beds of quartzite and shale just

[1] Emmons, S. F., Descriptive geology: U. S. Geol. Expl. 40th Par. Final Rept., vol. 2, pp. 345-348, 1877.

WASATCH FRONT AT PROVO, SHOWING SHORE LINE OF LAKE BONNEVILLE.



LONGITUDINAL OR STRIKE VALLEY SEPARATING MAIN WASATCH RIDGE AT PROVO PEAKS FROM THE FRONT HILLS.

east of the anticlinal axis in the lower canyon walls appear to be separated by a strong unconformity from the nearly horizontal limestone beds that form the upper walls, but examination of the whole length of the canyon proves[1] that the limestone beds also bend downward to the east and that the structure is an S-shaped fold with only its upper half exposed. In the Slate Creek area the conformable relation is at once evident. The structure here, too, is an anticline, a small band of limestone with west dip overlying the quartzite and shale on the west limb at the base of the slope.

The great limestone series that overlies the Ophir formation includes strata of Cambrian and Mississippian age, but no boundary between the two has been determined. No Cambrian fossils were found, but the prevailing shaly and mottled character of the lower beds and their stratigraphic succession are the same as in the Cottonwood and American Fork region to the north, where Middle Cambrian fossils have been found. The lowest fossils (*Zaphrentis*) suggesting Mississippian age were found about 1,600 feet above the top of the quartzite, but beds below this horizon have the lithologic character of lower Mississippian limestones. About 2,000 feet stratigraphically above the quartzite coarse-grained bluish-gray limestone of probable upper Mississippian age is present. This limestone forms the wall rock of the ore bodies in the Monarch mine. A short distance above this limestone the upper Mississippian consists of a thick series of intercalated limestone, shale, and quartzite, which caps the front hills and forms the lower west slope of the main ridge. The apparent enormous thickness of this intercalated series may be due in part to faulting, though no proof of faulting was found. The longitudinal, or strike, valleys separating the front hills from the main ridge owe their outline principally to the rapid erosion of soft strata, especially shaly carbonaceous limestones, in this series.

ORE DEPOSITS.

Although much prospecting has been done on a small scale and many finds of mineral reported at different times, ore has been shipped from only one property, the Monarch mine, owned by the Garden City Mining Co. of Provo. The ore of this mine and of a few small prospects is lead carbonate and galena with low silver and high iron content replacing limestone along fissures. Small amounts of gold in limonite are said to have been found in shallow surface diggings on the front hill south of Slate Creek, but none of these surface deposits have continued downward in paying quantities. The Bonneville tunnel, about a mile long, has prospected this ground at depth with negative results. It crosses the anticlinal axis south of Slate Creek, passing through quartzite and shale into limestone 4,000 feet from the portal.

The Monarch mine is on the upper north slope of Rock Creek Canyon near its mouth and is reached from the canyon bottom by a long winding trail. It is opened by an upper and a lower tunnel, about 130 feet apart in elevation, with drifts, crosscuts, and inclines in Mississippian limestone. The ore was conveyed to the canyon bottom by a long, narrow chute and thence hauled by wagon to the railroad at Provo. Outcrops of ore have been found on the steep canyon wall, and there is said to be a well-mineralized outcrop on the summit of the hill.

The upper workings are along two fissures, one trending N. 25° E. and the other S. 70° E. The workings on the latter extend 400 feet from an intersection with the former and have furnished most of the ore shipped. Ore has been found in bunches ranging from a few pounds to several tons in weight along the intersection of these fissures with certain beds, especially those of coarse grain, and in places of pronounced shattering. The lower workings have been opened to prospect these fissures at greater depth.

A prominent but undeveloped north-south fissure, stained with limonite and said to contain small amounts of ore minerals, outcrops west of the workings. It can easily be traced from the south side of the canyon across the bottom and up the north slope. In the lower part of the canyon, where the strata are vertical, the fissure coincides in position with the bedding, but along the upper north wall, where the beds have a low eastward dip, the fissure cuts obliquely across them, dipping about 60° E. Its intersection with the coarse-grained Mississippian beds is a favorable place for prospecting.

[1] Emmons, S. F., U. S. Geol. Expl. 40th Par. Final Rept., vol. 2, pp. 345-346, 1877.

Primary mineralization consists of a replacement of limestone by a mixture of white dolomite, scalenohedral calcite, galena, and presumably pyrite and zinc blende. Oxidation has been so thorough, however, that nearly all the primary ore minerals have been removed, and the ore mined is principally cerusite and reddish-brown iron oxide. Up to 1913 about 50 tons of ore had been shipped, averaging about 9 ounces of silver to the ton, 35 per cent lead, and 36 per cent iron. Samples of especially high-grade ore have yielded 16 ounces of silver to the ton, 76 per cent lead, and a little gold. Examination of the lower walls and floors of the stopes may prove the presence of oxidized zinc ore. This type of mineralization, characterized by a general absence of quartz and by a low silver content, is typical of lead-zinc deposits formed at considerable distances from intrusive igneous bodies. Distinction should be made between quartz deposited with the ore and chert nodules and lenses, which are a part of the limestone and are no indication of ore. It has formed workable bodies in the purer limestone beds and at places where favorable openings have been made by excessive shattering, but as a rule it has no noteworthy influence on dense hard or shaly limestone or on shale or quartzite. The most promising ground for prospecting, therefore, is along fissures filled with dolomite spar at their intersection with the coarse-grained beds of Mississippian limestone.

PAYSON DISTRICT.

By V. C. Heikes.

The Payson district, in Utah County, organized in 1871–72, is in the western foothills of the Wasatch Range and is 12 miles square, the town of Payson being near its center. Seventy locations had been made up to September, 1880, at which time only five, having 120 to 300 feet of cuttings, were in force. The country rock is limestone. The ore is low grade, carrying 12 to 15 ounces of silver. None was shipped previous to 1880,[1] and no production has been reported to the United States Geological Survey.

[1] Tenth Census U. S., vol. 13, p. 446, 1885.

SPANISH FORK DISTRICT.

By V. C. Heikes.

The Spanish Fork district is in Utah County, south of the Provo district. With the Cook district, it was organized during the mining excitement of 1871 and 1872. All the claims had been abandoned in 1880.[1] No metals are known to have been produced in the Spanish Fork district.

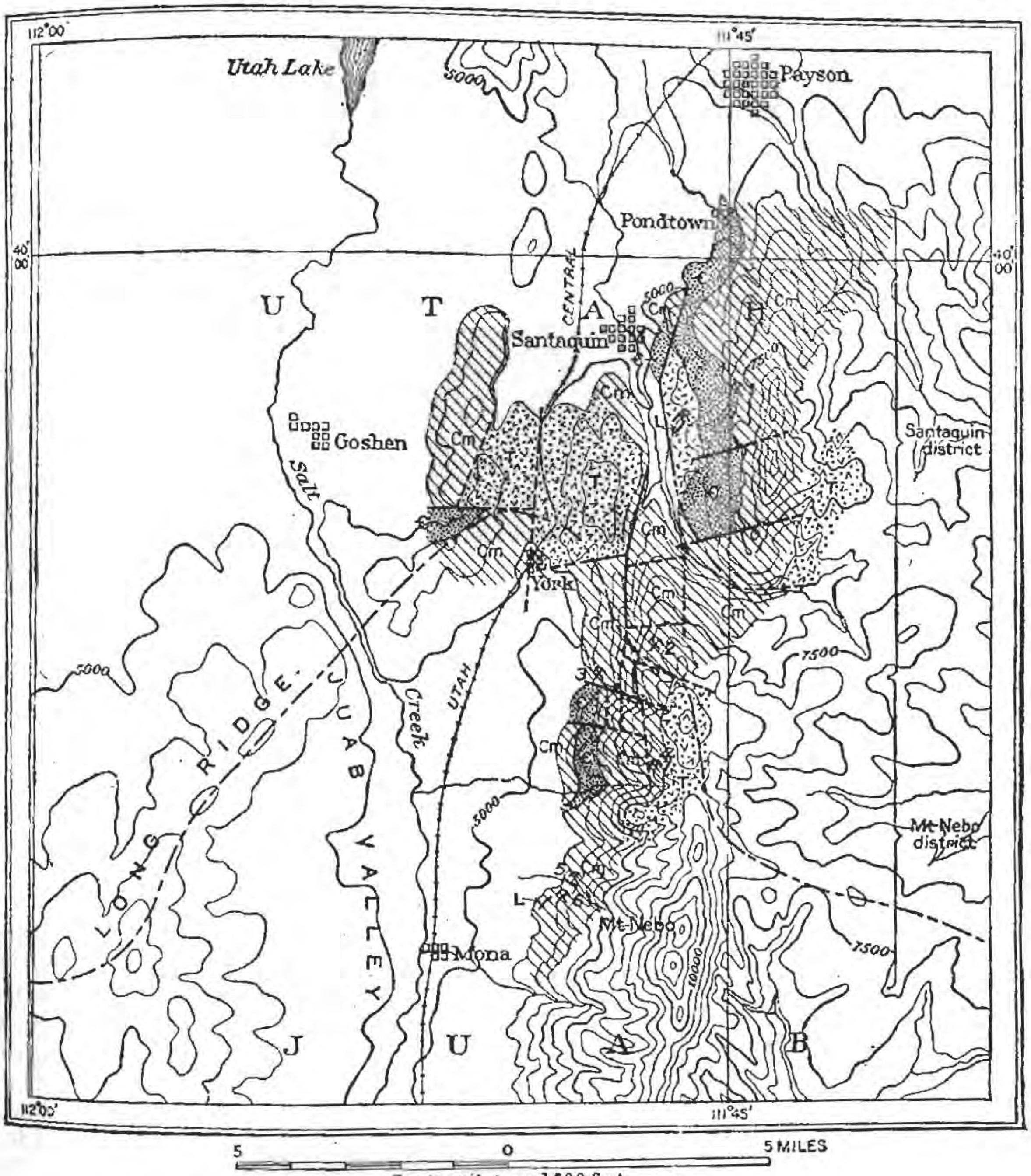
SANTAQUIN AND MOUNT NEBO REGION.

By G. F. Loughlin.

GEOGRAPHY.

The Santaquin district in Utah County and the Mount Nebo district in Juab County are contiguous and form a unit so far as geologic and economic conditions are concerned. (See fig. 40.) The mines and prospects lie in the southern part of the Wasatch Range, between latitudes 40° and 39° 15′ and along longitude 111° 45′. This part of the range includes a northern portion, locally called Santaquin Mountain, which has a maximum elevation of 10,000 feet and a length of 8 miles, and a southern portion, which culminates in Mount Nebo at an elevation of 11,871 feet and has a length of 15 miles. Mount Nebo is the second highest and the southernmost summit of the Wasatch Range. Occasionally it has been referred to as the highest peak of the range, but according to the Salt Lake topographic sheet of the United States Geological Survey Timpanogos Peak, between American Fork and Provo canyons, is higher, having an elevation of 11,957 feet. The Santaquin and Mount Nebo ridges are separated by Santaquin Canyon, which in its upper course cuts the range in an east-west direction but which in its middle and lower courses swings northwestward and northward, emerging at Santaquin in a nearly due north course. The south end of the Mount Nebo ridge is marked by Salt Creek, which separates the Wasatch from the San Pitch Mountains. Salt Creek crosses the line of the mountain axis in a due westward course and emerges in Juab Valley at Nephi, where it turns northward in a meandering course for 12 miles, cuts through the low northeast end

of Long Ridge in a bold canyon, emerging again south of Goshen, and continues through Goshen Valley, finally entering Utah Lake. southward from Salt Lake City to Nephi and towns still farther south. Santaquin is also reached by the Denver & Rio Grande Rail-



Contour interval 500 feet
Datum is mean sea level

FIGURE 40.—Geologic sketch map of Santaquin and Mount Nebo region. Æ, Pre-Cambrian granite; Ꞓ, Cambrian quartzite; Cm, Mississippian and earlier limestones; T, Tertiary conglomerate and volcanic rocks L, Lamprophyre dikes. Mines: 1, Union Chief; 2, Santaquin Chief and Santaquin King; 3, Big Nebo; 4, Eva and Nebo Highland; 5, Spider; 6, Freddie Lode (Eureka Leasing Co.).

Santaquin, Starr, and Mona, all farming towns, are the nearest to the different mines and are all reached by the "Salt Lake Route," or by the main wagon road which follows the valley road. Nephi, the county seat of Juab County, lies at the south base of Mount Nebo, 8 miles south of Mona, 18 miles south of Santaquin, and 70 miles due south of Salt Lake City.

GEOLOGY.

SEDIMENTARY ROCKS.

PRE-CAMBRIAN ROCKS.

The oldest formation in the region is a complex of pre-Cambrian granite-gneiss with schist inclusions (schistosity dipping east-northeast), that is exposed for 2 miles or more along the lower range front east of Santaquin. Its prevailing color is pink to reddish, varying according to its content of red alkalic feldspar. Its texture varies from coarse to rather fine grained and from strongly gneissic, with or without augen, to granitoid, with no megascopic indication of foliation. Its mineral composition varies from that of granodiorite to that of alkaline granite or alaskite. The minerals in order of abundance are plagioclase (sodic andesine) and quartz, which together make up 75 to 80 per cent of the rock, microcline about 15 per cent, chlorite (representing completely altered biotite) 5 to 10 per cent, and magnetite and apatite less than 1 per cent. All the principal minerals are in irregular grains and exhibit more or less strain effects but show no apparent crushing, or "flaser" structure indicative of shearing. The plagioclase is considerably sericitized. Pegmatite and aplite form sills along foliation planes and dikes across the foliation. Dikes and sills branch from each other, proving that they were intruded after the main body of gneiss had become sufficiently rigid to be fractured. The schist inclusions comprise micaceous, hornblendic, and feldspathic (plagioclase) types, all of which vary with the grain and amount of the injected granitic material. They lie, as a rule, parallel to the foliation of the intrusive gneiss but are cut both along and across their foliation planes by aplitic and pegmatitic material.

CAMBRIAN ROCKS.

The Cambrian rocks include a basal quartzite 800 to 1,000 feet thick, according to aneroid measurements, and perhaps 1,500 feet or more of shale, limestone, and dolomite. The principal exposure of the quartzite is a band that extends along the front of the Santaquin Ridge for 6 miles and rests unconformably upon the pre-Cambrian granite. Another prominent exposure extends along the base of the Mount Nebo Ridge for 2 miles northward from North Canyon, which lies due east of Starr. Two small exposures of the topmost quartzite beds was noted, one at the base of the main ridge in Wash Canyon, southeast of York, and the other on the west slope of the low hills northwest of York.

The quartzite varies from nearly white to different shades of pink, red, and brown, and from moderately coarse conglomerate to typical shale. The basal beds, resting directly on the gneiss complex, contain pebbles of quartz and coarse red feldspar identical in character with the pegmatitic material in the underlying formation. Above the basal beds both conglomerate and arenaceous beds are composed almost wholly of quartz, but the shaly beds as a rule are distinctly micaceous. Mud cracks, worm borings, and ripple marks are present in the shale. The pebbles are practically all of vein or pegmatitic quartz and a few contain seams with minute dark metallic grains. There is no regularity whatever to the alternations of conglomerate, quartzite, and shale beds. One horizon, near the middle of the quartzite, is characterized by dark, brown-weathering, ferruginous beds.

The quartzite passes upward into a band of greenish shale (see Ophir formation, p. 79), in which are several beds or lenses of dark-blue limestone, for the most part dense and shaly. Trilobites and small brachiopods resembling Cambrian forms of *Obolus*, said to have been found in the shale, were shown to the writer, but a hasty search for others was unsuccessful.

Above the shaly Ophir formation is a series of limestones, the lower 1,500 feet of which resembles the Middle Cambrian section of the Tintic district, 20 miles to the southwest, in lithologic character and stratigraphic sequence but is less than two-thirds as thick. It includes mostly dark shaly beds, some dolomitic members, and one white bed, about 40 feet thick and 650 feet above the quartzite. The next 800 feet also has characteristics suggesting Cambrian age; and the top 500 feet, a series of alternating light-gray and dark bluish gray dolomitic beds, has lithologic characters similar to the Cole Canyon (Middle Cambrian) and Bluebell (Ordovician) dolomites in the Tintic district (p. 398) but is thinner than either These limestones are found above the main quartzite exposures

throughout the region, and the upper members are also exposed along the low ridge which separates the Santaquin and Goshen valleys.

MISSISSIPPIAN (AND EARLIER?) ROCKS.

The Cambrian limestones are overlain by 500 to 600 feet of mostly dark-gray dolomitic limestone, in which no fossils were found but which are probably to be correlated with the lower Mississippian, though they may be older. Directly above them, on the Santaquin Ridge, in similar rock, characteristic Madison (lower Mississippian) fossils were found, which G. H. Girty, of the Survey, has identified as *Menophyllum* sp., *Syringopora surcularia?*, *Chonetes illinoisensis*, *Dielasma?* sp., *Spirifer centronatus*, *Euomphalus luxus*, and *Phillipsia* sp.

At a horizon nearly 400 feet higher, black chert nodules in dark thin-bedded limestone become characteristic, cherty and noncherty beds alternating. Fossils in this cherty horizon were found in abundance on the west slope of the high south peak of the Santaquin Ridge, where the following forms were collected by the writer and determined by Mr. Girty:

Cyathaxonia arcuata?
Bellerophon sp.
Rhombopora sp.
Fenestella sp.
Productella concentrica?
Rhipidomella dalyana?
Camarotoechia metallica.
Cliothyridina sp.
Michelina placenta?
Syringopora surcularia.
Menophyllum sp.
Productus gallatinensis.
Spirifer grimesi.
Spirifer centronatus.
Spirifer suborbicularis.
Amplexus.
Zaphrentis? sp.
Leptaena rhomboidalis.
Composita sp.
Phillipsia peroccidens.
Aulopora.
Chonetes illinoisensis.
Schizophoria swallowi.

The lower Mississippian forms most of the main upper parts of the Santaquin and Mount Nebo ridges. A small body of limestone with characteristic Madison fossils was found northeast of Santaquin, on the lower slope of the ridge, where it is apparently overridden by Cambrian quartzite. The fossils from this limestone were identified by Mr. Girty as follows.

Menophyllum sp.
Syringopora surcularia?
Schuchertella chemungensis.
Chonetes illinoisensis
Productella concentrica?
Productus sp.
Dielasma sp.
Spirifer centronatus.
Composita humilis?
Euomphalus ophirensis.
Euomphalus utahensis.

This limestone passes downward into limestone with Cambrian characteristics, and the latter in turn into shale and quartzite. The Cambrian limestone, however, appears remarkably thin, and it seems probable that a part of the section has been concealed by settling along a strike fault.

About 400 feet above the lowest black cherty beds near the crests of the main ridges are a few medium-gray coarse-grained limestone beds similar to that replaced by the great "Colorado Channel" ore body in the Tintic district. (See p. 399.) Fossils taken from these beds were identified as *Batostomella* sp., *Cystodictya* sp., *Fenestella* several sp., *Chonetes illinoisensis*, and *Rhipidomella dalyana?* by Mr. Girty, and referred tentatively to the upper Mississippian.

These beds alternate with black cherty beds, and no definite boundary therefore can be drawn between lower and upper Mississippian. Two hundred feet above these coarse-grained beds shaly and sandy strata are interbedded with dark dense limestone, which is still in part cherty, and form a series similar in lithologic character and stratigraphic position to the upper Mississippian strata which separate the lower Mississippian limestone from the Weber (Pennsylvanian) quartzite. No attempt has been made to measure the thickness of this series in the Santaquin and Mount Nebo region. The thickness varies greatly, ranging from a few hundred feet on the east slope of the Santaquin Ridge to probably a few thousand feet on Mount Nebo, the greater part of which appears to consist of this intercalated series. Portions of the upper Mississippian beds are exposed also below the southern end of the Cambrian quartzite of the Santaquin Ridge on the northeast side of Santaquin Canyon, on the low hills on the west side of the canyon,

and on the low western flanking ridge southeast of York and north of Wash Canyon. Fossil fragments, including a *Productus* of the *cora* group (probably a variety of *P. giganteus*), a *Fenestella*, a *Martinia* (?), and a *Loxonema* (?) were found in the exposures on either side of the lower Santaquin Canyon. These, according to Mr. Girty, are not sufficiently characteristic to serve as a basis for correlation, but so far as they go they accord with the lithologic character and stratigraphic sequence of the rocks, which are upper Mississippian. No Paleozoic strata of later age than Mississippian were seen in the district. The Weber quartzite and the Park City formation were evidently removed during an erosion interval which is expressed by a marked unconformity between pre-Pennsylvanian and Tertiary formations.

MESOZOIC ROCKS.

Mesozoic rocks, chiefly gray and red sandstones and shales with a few deposits of gypsum and rock salt, lie south and southeast of Mount Nebo but have not been studied by the writer. They have been tentatively correlated with the Jurassic formations because of their gypsum and salt deposits.[1]

TERTIARY ROCKS.

The best sections of Tertiary strata seen by the writer lie east of Santaquin Ridge and along the east slopes of the more northern summits of Mount Nebo Ridge, but time was too short to allow even a rough estimate of their thickness and sequence. Veneers of Tertiary rock are also present on the low red foothills (down-faulted blocks) east and west of the railroad between Santaquin and York. Both sedimentary and effusive volcanic rocks are present. The principal sedimentary types are a coarse conglomerate and a peculiar concretionary limestone, similar to that quarried for marble near Clinton, on the Denver & Rio Grande Railroad.

The conglomerate consists of pebbles, and in places even small boulders, mainly of quartzite, limestone, and black chert in a soft red sandy matrix. The quartzite pebbles include both Cambrian and upper Mississippian types, the Cambrian greatly predominating. The limestone pebbles include the shaly Cambrian types, dolomitic types of lower Mississippian and probably earlier age, and the coarse-grained gray limestone of upper Mississippian age. This variety of pebbles proves that almost the entire Paleozoic section was exposed to erosion while the conglomerate was forming. There is no evidence, however, that the pre-Cambrian rocks were exposed to erosion at this time. Owing to the tendency of the red matrix to rapid weathering, many outcrops of the conglomerate are reduced to an aggregate of loose pebbles and boulders in a soft red soil.

The limestone is bleached to white on the surface but is pink on fresh fractures, weathering to a bright-red residual soil. It consists for the most part of a dense matrix full of large and small gray to brown concretions, of such shapes as to suggest that they were mostly formed by accretion of calcium carbonate around nuclei of shells. Several forms suggesting the outlines of pelecypods and gastropods were found, and one undoubted gastropod was collected which T. W. Stanton, of the United States Geological Survey, thinks may be a fresh-water Eocene type. The limestone is chemically very impure, containing a large amount of red clay sand and even pebbles, and it is probable that it will be found on more thorough study to grade into the conglomerate. The concretionary limestone lies near and perhaps at the base of the Tertiary section, but its thickness and horizontal extent are not known. It was found east of the Santaquin Ridge, on the upper eastern slopes of the Mount Nebo Ridge and in the low hills between Santaquin and York.

IGNEOUS ROCKS.

VOLCANIC ROCKS.

The volcanic rocks are limited to a coarse agglomerate of andesite or latite cobbles in a soft matrix of tuff whose outcrops, owing to the rapid weathering of the tuff, are, like the Tertiary conglomerate, mostly reduced to aggregates of loose cobbles. They overlie the Tertiary sediments and are limited in the Santaquin and Mount Nebo region to the areas covered by these rocks; but to the west on Long Ridge and the East Tintic Mountains they lie beneath andesite or latite flows on rhyolite or on Paleozoic sediments. This difference in distribution suggests that the Eocene

[1] Boutwell, J. M., U. S. Geol. Survey Bull. 225, pp. 102-103, 1904, and Bull. 225, pp. 483-487, 1904.

sedimentary rocks of the Santaquin district did not extend west of the longitude of Long Ridge, and that Eocene sedimentation was stopped or interrupted, locally at least, by volcanic eruptions which are tentatively assigned to late Eocene or to Miocene age.

The andesite or latite cobbles vary from gray to dull black in color and from dense to glassy porphyritic in texture. Two varieties, augite andesite and hornblende-augite andesite, have been noted in thin section, but others may also be represented. These two varieties are generally similar in character to members of the volcanic series of the Tintic district, which are in large part, if not wholly, of latitic or monzonitic composition.

DIKES.

The only exposures of intrusive rocks studied by the writer are two small dikes of lamprophyre, one on the Black Balsam claim close by the granite-quartzite contact on the first spur south of the Union Chief mine east of Santaquin, the other on the south side of Bear Canyon, northeast of Mona. Besides these, prospectors have reported other "porphyry" dikes; but nothing is known of any large dikes or other forms of intrusive rock in the district.

The two dikes studied are very similar megascopically. Their color is dark gray to black, and their surfaces sparkle with shiny black phenocrysts of biotite, which range from mere specks up to tablets 3 to 4 millimeters in diameter in a dense groundmass. In thin section, the Black Balsam dike consists of a groundmass composed of glass and albite crowded with small phenocrysts of augite biotite, olivine, magnetite, and apatite.

In the dike on the south side of Bear Canyon the groundmass consists almost entirely of albite, and phenocrysts of olivine are absent. Chalcite, chalcedony, and pyrite are secondary minerals in both dikes. The character of both dikes is best designated by the name "albite minette."[1]

The lamprophyric character of these dikes suggests that they may be differentiates from the pre-Cambrian granite magma complementary to the aplitic phases; but their freedom from the mechanical and chemical alterations which characterized the pre-Cambrian rocks renders such a correlation quite unlikely.

So far as the character of their augite and biotite phenocrysts are concerned, the dikes have characteristics in common with the local effusive volcanic rocks and with the great volcanic series of the Tintic district, which is free from pronounced diastrophic alteration effects; but in the absence of calcic plagioclase phenocrysts they are strikingly different. While, therefore, there is little doubt that they belong to the great series of post-Eocene volcanic rocks they must be regarded as rather unusual members of the series.

STRUCTURE.

The rocks of the region have for the most part a homoclinal structure, with an easterly to northeasterly dip of near 30°. The strata northeast of Santaquin, however, dip northeast to north as if approaching an anticlinal axis; and those on the west slope and summit of Mount Nebo are sharply folded, with dips ranging from almost horizontal to vertical. The monoclinal structure is further complicated by overthrusts and block faulting.

FOLDS.

As the strata are for the most part homoclinal, it is in general fairly easy to estimate the depth to any special bed at any point. At Bear Canyon, however, northeast of Mona, and perhaps over a considerable part of Mount Nebo, the folding is more complicated. The mouth of Bear Canyon crosses the axis of an anticline which pitches south-southwest and whose west limb dips 45° or more westward, but whose east limb is vertical. Besides this asymmetric character, several thin-bedded or shaly strata are crumpled and locally pinched and swelled, causing the thickness of the section to vary from place to place. Three or four limestone beds in this vicinity have perhaps been replaced by ore, but their stratigraphic positions and probable underground extents can be properly determined only after very detailed geologic mapping.

[1] For detailed descriptions see Loughlin, G. F., Two lamprophyric dikes near Santaquin and Mount Nebo, Utah: U. S. Geol. Survey Prof. Paper 120, pp. 101-109, 1918 (Prof. Paper 120-E).

FAULTS.

Types.—The principal structural features in the Santaquin-Mount Nebo district are faults, including doubtful overthrusts of general north-south trend, and a series of north-south and east-west block faults of the "Basin Range" type. (See fig. 40, p. 323.) In addition, systems of mineralized fissures, some of which are accompanied by distinct faulting, trend mostly northeast and north-northwest, though some trend approximately north and some east. Mineralization of these fissures probably took place long after the overthrusts but before the period of Basin Range block-faulting.

Overthrusts.—The faults which are here described as overthrusts are in part so poorly exposed, their courses so nearly parallel to the north-south system of block faults, and the rocks along them so free from severe crumpling or crushing, that the writer is not fully convinced of their overthrust character. East of Santaquin the northern part of the pre-Cambrian granite appears to overlie quartzite, but the contact is concealed by débris. A little farther northward, however, the granite pinches out and the main body of Cambrian quartzite overlies a dark brecciated limestone, which passes downward into shale and quartzite. This lower quartzite exposure, in turn, overlies the fossiliferous Mississippian limestone (p. 325), which is very free from any of the crumpling or brecciation that is likely to accompany overthrusting. The Mississippian limestone is underlain conformably by Cambrian limestone and a third quartzite exposure.

The pre-Cambrian granite southward disappears beneath a high alluvial slope, now trenched by Santaquin Creek; but the main Cambrian quartzite body continues and at its southernmost exposure rests again upon fossiliferous upper Mississippian limestone, which, as northeast of Santaquin, is surprisingly free from contortions and crushing. Reverse or overthrust faulting alone seems to explain the positions of the rocks, but the absence of disturbance in the overridden limestone is not easily explained. It is, however, a striking feature throughout the Wasatch country that though shales and even the thinner-bedded quartzites are much contorted along fault zones the adjacent heavily bedded limestones are practically free from such deformations.

At the mouth of North Canyon, 8 miles south of Santaquin, an extremely brecciated and apparently nonfossiliferous limestone, which dips east beneath Cambrian quartzite, affords the most convincing evidence of an overthrust. A tunnel of the Excelsior Mining Co., driven through the limestone into the quartzite, was inaccessible at the time of the writer's visit. No fossils were found in the underlying limestone, but the presence on the dump of fragments of a highly carbonaceous and finely pyritic bed similar to two found elsewhere in the Mississippian of the southern Wasatch Mountains and the Tintic district, gives a clue to the age of the limestone and accords with the structural relations in showing the fault to be an overthrust.

Block faults.—The undoubted normal or block faults of the district are marked by longitudinal and to a less degree by transverse valleys, whereas those interpreted as overthrusts appear unrelated to topography. (See fig. 40, p. 323.) From Santaquin southward for about 8 miles, nearly to North Canyon, the western side of the range is composed of parallel ridges separated by remarkably straight north-south canyons. The strata on opposite sides of these canyons are quite discordant. For example, just north of Wash Canyon (2 miles south of York) the upper Mississippian strata with gentle easterly dip form the low western ridge, whereas pre-Mississippian limestones lie directly opposite on the west face of the main ridge and upper Mississippian strata form the crest, about 2,000 feet higher. Wash Canyon follows a nearly east-west fault, the upper Mississippian limestone north of it having the same altitude as Cambrian quartzite and limestones south of it. Farther south a second east-west fault cuts off the North Canyon overthrust. East of York, the upper Mississippian of the western ridge is separated at another east-west fault from the Eocene sediments and volcanic breccia, which cover the low hills west of Santaquin Canyon, whereas the face of the main ridge east of the canyon is made up of the pre-Cambrian complex and lower Paleozoic strata, and the Tertiary beds are found only along its eastern base. The most obvious east-west (N. 70° E.) fault in

the district .s that on the west side of the main ridge in a ravine 3½ miles south of Santaquin Canyon, where the entire Cambrian quartzite and the overridden Mississippian limestone end abruptly against the lower (probably Cambrian) limestone beds. The presence of Eocene conglomerate and late or post-Eocene volcanic agglomerate on these faulted blocks places the time of the faulting and Basin Range uplifts not earlier than Miocene. Block faulting on a smaller scale but in the same directions and probably of the same age is believed to be the cause of apparent discrepancies in thickness and stratigraphic sequence of the limestone series.

Mineralized fissures.—The mineralized fissures have not been traced on the surface, and underground developments as a whole are too few to afford an adequate idea of their persistence, origin, or arrangement in definite systems. The principal fissures east of Santaquin trend N. 40°–60° E., and those worked or prospected in the Mount Nebo ridge trend N. 25° W., N. 25° E., north, east-northeast, and east, and parallel minor fissures east of Santaquin. It can not be said whether the more persistent fissures have fairly uniform trends throughout the district, or whether there is more than one system of relatively persistent fissures. It is certain, however, that mineralization in several places has occurred along minor or branch fissures, a fact which prospectors should bear in mind.

In the Union Chief lower workings, one narrow, approximately east-west fissure containing calcite, barite, and a little galena, is offset a few feet at one place by a barren strike fault which probably belongs to the block fault series. This is the only place in the district known to the writer where a contact between a mineralized fissure and a postmineral fault has been definitely exposed, though evidence in the Eva mine also suggests a postmineral fault. These occurrences, however, show that ore bodies are likely to be offset by faults and so add to the difficulties of mining, but it is possible, by careful study of the thickness and sequence of limestone beds and their displacements on the surface, to determine the amount and direction of such faults.

ORE DEPOSITS.

The ore deposits comprise veins and bedded replacement deposits of lead, zinc, and copper, only the first two of which have yet been found in commercial quantity. The copper deposits are believed to be genetically connected with those of lead and zinc, but their distribution and mode of occurrence are sufficiently distinctive to warrant separate description.

COPPER DEPOSITS.

The copper deposits thus far prospected are thin veins and stringers of chalcopyrite accompanied by specularite, chlorite, and quartz that follow fissure zones in the pre-Cambrian granite (gneiss) and in the Cambrian quartzite and shale.

The Sally Ann prospect, situated beside the Union Chief road in Green Canyon, has opened a mineralized fissure zone in the granite that strikes about N. 15° E., and is bounded by two well-defined slickensided walls about 15 feet apart. It is crossed by an east-west joint, also with slickensided walls. Both walls and the cross joint carry stringers of chalcopyrite partly altered to the green carbonate, malachite, and the red oxide, cuprite. The moderately shattered rock between the walls contains a small sprinkling of copper minerals. The gangue minerals are vein quartz, which in places lines small vugs, and the minerals of the altered granite. The chalcopyrite tends to occur separately from the vein quartz, though both may be present in different parts of the same short stringer, and partly replaces the minerals, especially the plagioclase feldspar, of the granite. The malachite also, in thin section, shows a tendency to replace plagioclase.

The Copper Bullion prospect in the second or third draw north of the Sally Ann follows a shear zone in the granite parallel to the northeast dip of the foliation. The shear surface is undulating, and is bordered for a few inches on either side by almost microscopic fractures filled with finely micaceous chlorite and specularite in microscopic grains which give the rock a. dark-greenish color. Microscopic quartz and sericite are also present in the fractures, and with the other vein minerals impregnate the granite. Minute pyrite crys-

tals are associated with these minerals in the veinlets, especially in the impregnated rock. A little green copper stain appears here and there and suggests the presence of a small amount of chalcopyrite.

The Santaquin Central (Brownstone) tunnel, in the upper north slope of Magee Canyon east-northeast from Santaquin, has exposed similar mineralization in a shale member of the Cambrian quartzite. A small quartz vein, which in some places pinches out and in others swells to 4 inches, follows a slickensided strike fissure in the shale. The quartz shows the effects of slickensiding, and the immediately adjacent wall rock is altered to a felty or finely micaceous mass of chlorite, in which are disseminated minute crystals of pyrite. Some small lumps of chalcopyrite lie along the contact between the vein quartz and the chlorite, and in thin section specularite and sericite are seen. The minerals are all more or less intergrown, though pyrite and quartz appear for the most part to have formed before the other minerals.

The mineralization in these prospects may have been little more than hydration of the granite, accompanied by more or less transfer and concentration of the constituents to favorable places along fissures. The water presumably contained sulphur in some form capable of forming pyrite and may have also introduced the copper, but the total amount of copper in any of the veins studied is so small that it may be ascribed to leaching from the pre-Cambrian rocks along the mineralized fissures. The next vein described, however, which is intermediate in character between the copper and the lead-zinc deposits, can not be attributed to strictly local origin and suggests that all the deposits are genetically connected.

The Black Balsam vein outcrops near the crest of a spur a little east of the Sally Ann, and has been prospected by a short tunnel, inaccessible when visited. The wall rock is more or less shattered pre-Cambrian granite cut by a black lamprophyre dike 3 feet thick. The vein which lies close by the dike, though not found in contact with it, trends northeast and dips about 70° SE. The vein minerals are coarse-grained white calcite with a considerable though subordinate amount of fluorite, a few small oxidized grains of chalcopyrite (and pyrite?), and some green copper staining. A little dolomite was also noted in thin section. The vein minerals impregnate and replace the more crushed portions of the granite, giving the vein a gradational rather than a sharp contact. The vein minerals have intergrown contacts with one another, though the dolomite and calcite appear as a rule to have finished crystallizing before the fluorite. No lead minerals were noted by the writer, but an assay of a picked sample from the vein in the tunnel is said to have yielded 18.2 per cent copper, 8 per cent lead, 0.4 ounce of silver, and a trace of gold per ton. The metallic contents are thus intermediate between those of the copper and the lead-zinc veins. The gangue minerals may also signify an intermediate character, for fluorite in other Utah districts is commonly associated with quartz and copper ore, and calcite and dolomite are characteristic of lead or lead-zinc deposits. The local evidence in itself is far from convincing, but if compared with evidence in other districts strongly suggests this intermediate character.

LEAD-ZINC DEPOSITS.

OCCURRENCE.

The lead-zinc deposits, both in veinlike and in bed replacement forms, are confined to the limestones. Certain limestone beds, those most free from clay impurities and of granular rather than dense texture, are the most favorable and contain small bunches to rather large bodies of ore. Such beds are found throughout the limestone section. The coarse-grained beds (p. 325) are by far the most favorable, the dense argillaceous limestone commonly carrying ore only in narrow fissure fillings.

SANTAQUIN RIDGE.

Union Chief mine.—The workings of the Union Chief mine east of Santaquin are in Cambrian limestone, and the productive ground to date is limited to the upper workings, in strata which lie 400 to 550 feet above the top of the quartzite. The lowest stopes or better pockets are about 150 feet below the upper tunnel at the base of the main inclined winze, and have yielded mixed galena and lead carbonate ore which is said to run 20 to 50 and rarely over 100 ounces per ton in silver. In a raise just above the base of the winze the ore forms small bunches along a N. 50° E. fissure with 50°–70° SE. dip, having for the most part

filled openings in shattered impure limestone and been concentrated to some extent by oxidation and by the dissolving away of some of the limestone fragments by downward circulating waters. Bunches or lenses of coarse-grained massive calcite are also present, a little of which carries galena but most of which is barren. At the base of the raise and close by the winze the N. 50° E. fissure is intersected by a N. 30° W. fissure, dip 60°–80° W., along which a thin bed of dark-blue dolomitic limestone very free from clay impurities has been replaced for a short distance. Eighty feet below the upper tunnel, in a small winze near the main incline, a fissure which strikes N. 10° W. and dips 63° W. is bordered by soft yellow clay, residual after impure limestone, in which are embedded lumps of galena and lead carbonate which run 3 to 5 ounces in silver. The ore is accompanied by some silicification of the limestone. Eighty feet west of the incline on the same level a fault that trends N. 60° E. and dips about 60° NW. carries a decomposed body of vein quartz and earthy iron oxide, which assays 16 per cent lead and 2 ounces silver. At the intersection of this fault with a west-northwest fissure, where the dip of the rock is locally reversed and forms a trough, a favorable bed has been replaced by a small body of galena (with lead carbonate) and calcite. The replacement body extends east-southeast along the fissure for 20 feet and stops against a north-northeast fault with steep west dip, probably a branch from the fault that trends N. 60° E., which carries a little ore. On the 40-foot level at the intersection of two fissures that strike N. 70° W. and N. 25° E., respectively, a bedded replacement has been stoped over an area 20 feet square—the largest stope seen in the mine. The ore is said to have assayed 12 per cent lead and 2 ounces or less silver. The high silver content on the 150-foot level strikingly contrasts with the lower tenor on the 80 and 40 foot levels and is evidently in large part the result of enrichment. No comparative assays of pure galena ores have been made and nothing definite is known as to the changes in silver content with depth. The generally decomposed conditions of the wall rocks prevents a proper estimate of the amount of silicification which accompanied ore deposition. So far as could be seen the ore is as a whole intermediate between the siliceous and nonsiliceous types.

In the lower tunnel workings no workable ore has been discovered, though several approximately east-west stringers of calcite with a little galena and one with a little barite and copper minerals also have been found cutting dense impervious limestone.

Blue Eagle and White Dragon prospects.—On the south slope of the south peak of the Santaquin Ridge, a few small outcrops of oxidized ore have been prospected on the Blue Eagle and White Dragon claims. The ore lies in local enlargements of small northeast-southwest fissures which cut dense, black, cherty limestone of lower Mississippian (Madison) age. The Blue Eagle ore is a porous mass of lead carbonate intergrown with microscopic quartz and in places stained by a greenish-yellow earthy material that has the qualitative composition of vanadinite. The intergrown character of the lead carbonate and quartz suggests that they are both of secondary origin. The White Dragon ore consists of coarse-grained calcite inclosing grains of lead carbonate. The calcite around small vugs terminates in flat rhombs, or platy crystals, which are a typical associate of secondary ore. The absence in these prospects of undoubted primary ore suggests that the lead carbonate together with the quartz and calcite may be the product of local downward leaching from an ore body now completely removed by erosion. The presence of several veins and pockets of columnar and scalenohedral calcite, which are characteristic accompaniments of primary ore but which trend north or north-northeast and are cut by the lead carbonate fissures, lends weight to this suggestion. The original ore body may have been a bed replacement at the intersection of the primary calcite fissures with a favorable coarse-grained limestone bed that formerly lay about 200 feet above the present outcrops. The existence of such ores due to downward leaching, which are likely to form small local bunches along water-courses, should lead to caution in prospecting. No prospecting has been done in the coarse-grained beds.

Several other prospects along Santaquin Ridge have rather encouraging and others discouraging surface showings. Only one or two

have been very extensively developed, and none has yet found ore in commercial quantity.

MOUNT NEBO RIDGE.

Big Nebo mine.—The Big Nebo mine is about a quarter of a mile south of Wash Canyon, near the base of the range. The ore body has been stoped along a N. 25° W. vein that dips 60°–80° E. in Cambrian limestone. The stoped portion is pod-shaped, with an average width of 4 feet, and pitches steeply southward parallel to the slickensides on the walls. The ore, lead carbonate carrying silver and having an average value of $36 a ton, was followed down an incline for a short distance, but operations along the vein were suspended with a view to reaching it through a lower tunnel. The mine was idle when visited.

Santaquin Chief mine.—The Santaquin Chief mine is on the upper slope of the main ridge east of lower Wash Canyon and is reached by trails either from Wash Canyon or from Pole Canyon, which lies due south of Santaquin. The ore body forms a pipe in lower Mississippian limestone at the junction of a north-south with an east-west fissure, and had, when visited, been followed to a depth of 210 feet below its outcrop. The ore is coarse to fine-grained galena, more or less altered to lead carbonate in a quartz-calcite gangue. The quartz forms dense masses replacing limestone, and small crystal druses, which appear to be secondary, around pockets. The calcite in part occurs with the quartz, massive calcite serving as a groundmass for quartz crystals, and also in veins which cut the quartz and presumably fill fractures opened during a late stage of primary mineralization after quartz deposition had been completed. The calcite in both occurrences tends to form characteristic long-pointed crystals, scalenohedrons, along openings. In thin section the quartz is seen to be accompanied by some sericite and chlorite, a few small granules resembling anatase or titanite, a few resembling fluorite, and fine grains of iron oxide probably after pyrite. The replacement quartz contains isolated grains and small patches of galena with pronounced cubic cleavage. The fine-grained galena tends to form streaks or narrow lenses which lie both within the quartz and along the edges of the quartz and tend to work into the calcite and limestone. The lead carbonate occurs in all stages from alteration rims around galena to complete replacements of it. No zinc minerals had been reported in 1912, but were later said to occur along the walls of the vein.

Santaquin King mine.—The Santaquin King workings are on the slope above those of Santaquin Chief. The surface showing is a zone of calcite veinlets trending east to east-southeast in broken limestone along the footwall side of a fault. Small amounts of lead minerals have been found associated with the calcite. The country rock in a tunnel, which was 80 feet long at time of visit, is the dense black cherty Mississippian limestone, which includes a dark carbonaceous bed of almost coal-like appearance. The favorable coarse-grained limestone beds outcrop about 200 feet above the tunnel mouth and have not been systematically prospected.

Eva mine.—The Eva mine is on the north slope of North Canyon near the crest of the main ridge. The ore is a replacement of the coarse-grained limestone of probable upper Mississippian age. Three such beds dip about 20° S. 75° E., and are said to be mineralized; but only the uppermost of the three has been stoped. This bed, which is somewhat dolomitized, lies about 150 feet below the lowest quartzite bed of the upper Mississippian and is overlain by a fine-grained highly carbonaceous and argillaceous bed locally called the "velvet lime." This impervious bed marks the upper limit of mineralization but is more than 10 feet above the ore shoot.

The ore lies along the bedding in parallel layers more or less separated by unreplaced rock which is ribboned with short veinlets of coarse white dolomite and calcite spar. The spar veinlets are also present between the ore and the hanging wall. Fissures in the ore body trend nearly north and also N. 70° E. They are more or less filled with white spar, which varies from coarse massive to columnar or "onyx-like" in texture and forms long-pointed crystals (scalenohedrons) around pockets. The spar itself contains little if any metal, but the thicker parts of the ore body lie along the spar-filled fissures. The ore body stops against a fault fissure which trends N. 25° E. and dips steeply west. The direction and amount of displacement along the fault had not been determined. The greater part of the stoping has been along the west or

hanging side of the fault. The ground east of the fault is practically unprospected. It seems probable that the fault fissure was the main channel through which the ores were introduced and that the other fissures served to spread the solutions through the replaceable bed. The ore, however, along the fault is so oxidized that it may have been leached downward into the fault, and, if so, there is nothing to prove the relative age of the fault. According to either view, however, conditions for underground prospecting are the same, as they involve the location of the replaceable beds on both sides of the fault. The possible occurrence of good ore bodies on the east side of the fault is likely to depend upon the amount of minor fissuring through which the solutions could have spread along replaceable beds. The ore is composed of residuary lumps of coarse to fine grained galena in lead carbonate and of secondary zinc minerals. The most abundant zinc mineral is the carbonate, smithsonite, but the dense white basic carbonate-hydrozincite, and the hydrous silicate, calamine, are also conspicuous. No zinc blende was found, but its former presence may be marked by rusty cavities associated with practically unaltered galena. The zinc minerals are in part segregated from the lead ore and mined separately, and in part mingled with the lead minerals.

The ore is divided into three classes, according to the relative proportion of silver, lead, and zinc, but the average tenor of the ore of each class could not be learned. The better grades are said to contain as high as 20 ounces of silver per ton.

Eureka Leasing & Mining Co.'s claims.—On the south side of the mouth of Bear Canyon, northeast of Mona, is the group of claims operated by the Eureka Leasing & Mining Co. (in 1912). Three or more ore bodies have been worked. The ore and gangue are of the same type as that of the Eva mine, except that some primary zinc blende still remains. The ores are classified according to lead and zinc contents and as a rule run low in silver, assays showing 2 to 14 ounces per ton. The ore bodies, except the Freddie lode, are replacements of the coarse-grained upper Mississippian limestone along fissures. In the only stope being worked during the writer's visit the bed dips about 45° and the fissure somewhat more steeply, and the oxidized zinc ore tends to concentrate in the bottom part. In other stopes, including the old Burriston workings and the Spider property on the north side of the canyon, both bed and fissure are practically vertical. The Freddie lode, which has been stoped through a low spur at the canyon edge, follows an east-west fissure, the ore occurring in bunches in the vein and in small replacement bodies in a rather fine grained limestone. This limestone is immediately underlain by a coal-black carbonaceous and phosphatic bed, on which the largest bunches of ore stoped rested. Another good-sized pocket of ore lay at the intersection of the east-west vein with a north-south calcite vein. The phosphatic bed contains 10 to 15 per cent of phosphorus pentoxide (P_2O_5).

CONCLUSIONS.

Although the copper deposits as a rule occur in siliceous rocks and the lead-zinc deposits in limestone the two types are transitional in character and were doubtless formed at the same period. The small size and scarcity of the known copper shoots and the very small amount of alteration or replacement of the walls offer little encouragement to copper mining.

The lead-zinc deposits as a whole are transitional from siliceous to nonsiliceous, though shoots of nonsiliceous ore are the more numerous. These deposits as a rule are characterized by low silver content. The relatively high silver content, in some shoots 20 ounces to the ton, is attributed to secondary concentration during oxidation. The nonsiliceous variety of ore has formed relatively extensive shoots only where pronounced shattering or particularly favorable limestone beds have afforded opportunity. The most extensive ore bodies are where mineralized fissures have intersected the coarse-grained upper (?) Mississippian limestone beds; but even these are small in comparison with the average mines of the more important districts of the State.

PRODUCTION.

By V. C. Heikes.

The region includes the Santaquin, the Mount Nebo, and the Mona mining districts. The Mona, however, has no metalliferous deposits of importance.

SANTAQUIN DISTRICT.

The Santaquin district, in Utah County, organized in 1871, occupies a nearly square area measuring about 6 miles on a side, east of Santaquin, a station on the Los Angeles & Salt Lake Railroad. The United States Geological Survey has no records of any production previous to 1901. From 1910 to the end of 1917 470 tons of lead sulphide ore was produced, yielding 3,449 ounces of silver, 208 pounds of copper, and 206,522 pounds of lead, valued in all at $11,639.

MOUNT NEBO DISTRICT.

The Mount Nebo or Timmons district in Juab County, on the western slope of Mount Nebo, along the foothills and across Bear Canyon, was organized October 25, 1870. At that time the nearest railroad communication was American Fork, 62 miles distant. Wheeler [1] says:

> The principal mines are the Mountain Queen, shaft 30 feet; Olive Branch, tunnel 120 feet; Hague lode, Revolution, Atlantic, Aspenwall, Great Western, Monitor, Sultana, Olive Branch No. 2, Chicago lode, Little Agnes, St. Patrick, and Lily. * * * There is very little water in the immediate vicinity of the mines. * * * On the southern slope of Mount Nebo and apparently within this district are two large gypsum and one large salt (rock) deposits.

In September, 1880, Huntley [2] reported:

> The Mount Nebo district * * * is situated on the western slope of Mount Nebo and the adjacent portions of the Wasatch Range, extending 15 miles north of Salt Creek. About 130 locations have been made, 10 of which * * * are still held * * *. The country rock is limestone. The ore is an ochery carbonate and galena, assaying from $10 to $30 silver and 55 per cent lead, and occurs in narrow-bedded veins.
>
> The principal claims are the Olive Branch, Mount Queen, Germania, and Centennial, each having a few hundred feet of cuttings. Only 30 tons of ore have ever been shipped.

Since 1903 the United States Geological Survey has recorded the production reported from the district.

Production of Mount Nebo district, 1870–1917.

Year.	Ore (short tons).	Gold.		Silver.		Copper.		Lead.		Recoverable zinc.		Total value.
		Fine ounces.	Value.	Fine ounces.	Value.	Pounds.	Value.	Pounds.	Value.	Pounds.	Value.	
1870–1880[a]	30	....	....	900	$1,111	....	....	33,000	$1,815	....	....	$2,926
1881–1902[a]	400	....	....	6,000	5,070	....	....	160,000	6,512	....	....	11,582
1903	15	....	....	370	200	....	....	3,523	148	....	....	348
1907	102	0.69	$14	741	489	....	....	73,825	3,913	....	....	4,416
1908	70	....	....	2,450	1,299	....	....	49,000	2,058	....	....	3,357
1909	27	....	....	82	43	....	....	12,469	536	....	....	579
1910	30	....	....	585	316	....	....	23,674	1,012	....	....	1,358
1911	262	.97	20	3,607	1,912	....	....	204,523	9,204	11,359	$647	11,783
1912	1,429	10.61	220	16,152	9,933	472	$78	832,246	37,451	233,668	16,123	63,805
1913	616	2.10	44	2,920	1,764	333	52	256,188	11,272	131,749	7,378	20,510
1914	127	.04	1	624	345	247	33	75,180	2,932	16,283	830	4,141
1915	397	.53	11	547	277	128	23	60,736	2,855	206,229	25,573	28,739
1916	427	.35	7	1,903	1,252	247	61	100,822	6,957	163,350	21,889	30,166
1917	133	....	....	345	284	99	27	47,497	4,085	26,041	2,656	7,052
	4,065	15.29	317	37,220	24,295	1,526	274	1,932,683	90,780	788,679	75,096	190,762

a Estimated.

MONA DISTRICT.

The Mona mining district is in the northeastern part of Juab County, near the town of Mona, on the Los Angeles & Salt Lake Railroad, about 83 miles south of Salt Lake City. Most of the mining is for gypsum.

LAKE MOUNTAINS.

By G. F. LOUGHLIN.

The Lake Mountains have a north-south length of about 17 miles and a maximum width of 6 miles. They lie between Utah Lake on the east and Cedar Valley on the west.

[1] Wheeler, G. M., U. S. Geog. Surveys W. 100th Mer. Prog. Rept. for 1872, pp. 25–28, 1874.

[2] Precious metals: Tenth Census U. S., vol. 13, p. 460, 1885.

There is no known record of ore produced from these mountains, though some prospecting has been carried on. Only the north and south ends of the ranges were visited.

GEOLOGY.

At the north end, which includes the Lehi mining district, the rocks of the eastern slope consist of bluish-black dense and mostly thin-bedded fossiliferous limestones of upper Mississippian age, which dip about 20° SW. Fossils collected by the writer were determined as follows by G. H. Girty, of the United States Geological Survey, who states that the strata containing them can safely be placed in the upper Mississippian:

Stenopora sp.
Spirifer increbescens.
Productus pileiformis.
Batostomella sp.
Fenestella sp.
Cliothyridina sublamellosa.
Diaphragmus elegans.
Zaphrentis sp.
Spirifer keokuk var.
Derbya kaskaskiensis?

These strata belong to the series which lies beneath the Pennsylvanian quartzite and which, in the Wasatch and Oquirrh mountains and in the Tintic district, is characterized by alternating beds of limestone, shale, and limy quartzite. The shale and quartzitic beds are very scarce or absent in the northern Lake Mountains, as well as in the northern part of the East Tintic Mountains, 15 miles to the southwest. Although no quartzite was found in place the great number of quartzite cobbles and boulders in the canyons and eastern alluvial slopes indicates that the Pennsylvanian quartzite is probably present along the backbone and western slope of the northern part of the range.

LEHI DISTRICT.

The Lehi district, organized January 11, 1894, is in Utah County, southwest of Lehi, a station on the Denver & Rio Grande Railroad and the Los Angeles & Salt Lake Railroad. The district borders the west shores of Utah Lake. Marble, "onyx marble," and clay are the predominating useful mineral products found.

The only evidences of mineralization seen by the writer are a few veinlets of columnar (scalenohedral) calcite. These veins, although accompanying or lying near ore bodies in some places, are by no means sure indications of ore, and the type of ore which they accompany is very unlikely to form deposits of industrial importance in so dense and impervious a rock as the local limestone. Some fabulously high assays of samples from this district at one time caused considerable excitement but proved to be fraudulent. Nothing of value was ever found.

NORTH TINTIC DISTRICT.[1]

The southern end of the Lake Mountains is included in the eastern part of the North Tintic district. The rocks here have an irregular anticlinal structure, lying nearly horizontal with slight undulations for nearly the entire width of the range (about 2 miles) but curving sharply to a nearly vertical dip in the easternmost exposures. The strata seen correspond in character to the Pine Canyon limestone of the Tintic district, which is mostly of lower Mississippian (Madison) age, but whose upper beds are tentatively correlated as upper Mississippian. At the Wanless, the only active prospect visited, a shaft had been sunk 75 feet in coarse-grained limestone similar to that containing the "Colorado Channel" ore body in the Tintic district. Some veins of white columnar calcite, or travertine, accompanied by some soft red iron oxide, were exposed in the bottom of the shaft.

OQUIRRH RANGE.

By B. S. Butler.

GEOGRAPHY.

The Oquirrh Range extends southward from Great Salt Lake for about 30 miles in Salt Lake, Utah, and Tooele counties. In its southern portion it is about 10 to 12 miles wide but in its northern portion it is scarcely half as much.

In common with most of the basin ranges the Oquirrh Range rises steeply from the flat valley bottoms to the crest of the range. Its highest portions are more than 10,000 feet and most of its crest is more than 8,000 feet above sea level, or from 3,000 to 5,000 feet above the bottoms of the intermontane valleys. Near the central portion of the range low extensions run both

[1] See also p. 415.

eastward and westward. The range has been carved by erosion into long spurs that extend from the crest to the desert and are separated by deep canyon-like valleys.

Only the larger valleys contain perennial streams, and none of these furnishes a large supply of water. Bingham, Butterfield, and Fairfield canyons on the east side of the range and Ophir, Soldiers, and Tooele canyons on the west side contain streams. The surface water is not sufficient for large agricultural operations, or even for mining, but it has been supplemented in recent years by flow from the deeper drain tunnels.

Timber was present in many of the canyons in the early days but is at present almost entirely lacking, and mining needs are supplied from other sources.

PHYSIOGRAPHY.

The Oquirrh Mountains are in a more advanced stage of erosional development than many of those in the Great Basin region, and the cause for their elevation is correspondingly obscured. Folding is now the most conspicuous structural feature, but the fact that the general trend of the range is north and the fold structure northwest suggests that the present mountains have been carved from a fault block uplifted along its western edge and that the folds are part of an older structure that has been truncated by the fault. Gilbert [1] has described a fault later than the Lake Bonneville deposits along the west side of the range, and an earlier movement or movements along this same line would account for the present outline of the range.

Striking minor physiographic features of the range, especially around the northern end, are the beaches and terraces of the ancient lakes and the conspicuous bar at Stockton.[2]

GEOLOGY.

SEDIMENTARY ROCKS.

The sedimentary rocks of the range vary in age from Cambrian to Carboniferous. Quartzites and limestones are the most abundant, though some shales are also present.

The oldest rocks known in the range are the quartzite beds in Ophir Canyon, whose exposed thickness is about 500 feet. Overlying these is a series of shales and limestones about 100 feet thick. Fossils collected from these beds were determined by L. D. Burling as *Obolus (Westonia) ella* (Hall and Whitfield) and *Ptychoparia*, and the series is probably to be correlated with the Lower Cambrian Pioche shale. *Olenellus gilberti* has been found in collections brought in by the Wheeler Survey.[3] Overlying this limestone-shale formation is about 1,200 feet of strata composed largely of rather heavy-bedded limestone with some shaly and siliceous beds. A fossil, found by the writer a few hundred feet from the base, was determined by Mr. Burling as probably Cambrian. Gansl and Keefe [4] state that the entire 1,200 feet is of Cambrian age, and Gilbert [5] states that Carboniferous fossils were found separated from the Cambrian shales by less than 400 feet of limestone beds. In the Tintic district, which is in a southward extension of the Oquirrh Range, about 2,000 feet of Cambrian sediments overlie the great quartzite, which suggests a considerable thickness in the Oquirrh Range. It is evident that more data are needed to determine finally the age of these beds.

Above these unfossiliferous or sparsely fossiliferous strata are beds containing abundant Carboniferous fossils. At the base these are mainly limestones, but they pass into a series of interbedded limestones and quartzites. Spurr [6] has estimated the thickness of Carboniferous sediments in the Mercur basin as 12,000 feet, and the total thickness from the base of the known Carboniferous to the Bingham quartzite is doubtless several thousand feet greater than it is in the Mercur basin.

The lower horizons from which fossils were collected (near the Cliff mine in Ophir Canyon and north of the Ophir-Dry Canyon divide) yielded a fauna determined by G. H. Girty as Madison. It included the following forms:

Schuchertella chemungensis.
Chonetes illinoisensis.
Spirifer centronatus.
Spiriferina solidirostris.
Loxonema sp.

[1] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, p. 352, 1890.

[2] Idem, pl. 20.

[3] Walcott, C. D., Correlation papers—Cambrian: U. S. Geol. Survey Bull. 81, p. 319, 1891.

[4] Gansl, G. C., and Keefe, G. A., The Ophir mining district: Salt Lake Min. Rev., vol. 12, p. 17, July 30, 1910.

[5] Gilbert, G. K., U. S. Geol. Surveys W. 100th Mer. Rept., vol. 3, p. 28, 1875.

[6] Spurr, J. E., Economic geology of the Mercur mining district, Utah: U. S. Geol. Survey Sixteenth Ann. Rept., pt. 2, p. 377, 1895.

Euomphalus utahensis.
Syringopora? sp.
Zaphrentis sp.
Cystodictya sp.
Chonetes sp.
Productella concentrica.
Dielasma sp.
Eumetria marcyi.
Cliothyridina crassicardinalis.
Paraparchites sp.

From collections made between Dry Canyon and Soldiers Canyon on the west side of the range, the following fossils were determined by Mr. Girty and provisionally referred to the upper Mississippian:

Fenestella several sp.
Cystodictya sp.
Rhombopora sp.
Productus aff. P. parvus.
Productus laevicosta.
Spirifer keokuk var.
Spiriferina sp.
Cliothyridina hirsuta.
Cliothyridina incrassata?
Monophyllum sp.
Cystodictya sp.
Hemitrypa sp.
Rhipidomella ? sp.
Rhipidomella aff. R. dubia.
Batostomella sp.

Fossils collected from just north of Soldiers Canyon were determined by Mr. Girty as *Productus semireticulatus*, *Marginifera splendens*, and *Spirifer cameratus*, all of Pennsylvanian age.

Although more detailed work is necessary to determine the thickness of the divisions represented in the great limestone and the series of interbedded limestone, shale, and sandstone, it seems probable that fully one-half of the total thickness belongs to the lower Carboniferous or Mississippian.

Overlying the great limestone and series of interbedded limestone, shale, and sandstone is the Bingham quartzite, composed mainly of quartzite and sandstone with interbedded lenses of limestone. Keith [1] estimates the thickness of this formation as probably 10,000 feet in the Bingham district. The Bingham quartzite is the highest formation known to be exposed in the Oquirrh Range, though phosphatic beds in the northern part of the range are supposed to lie at the same horizon as those above the Weber quartzite in northern Utah and Idaho.

[1] Keith, Arthur, Areal geology of the Bingham mining district, Utah: U. S. Geol. Survey Prof. Paper 38, p. 35, 1905.

The apparent thickness of the Carboniferous rocks in the Oquirrh Range is much greater than in the neighboring ranges, and it is possible that this is due to faulting that has not been detected.

IGNEOUS ROCKS.

The igneous rocks of the Oquirrh Range are both intrusive and extrusive. The extrusive rocks, which are confined to the eastern foothills and the spur extending eastward near the central portion of the range, consist of flows and breccias of andesitic and latitic composition. The intrusive rocks include stocks, dikes, and sheets and are present in greater or less amounts from the Bingham district to the south end of the range.

The only large bodies of intrusive rock are the stocks of the Bingham district, with which are associated many smaller bodies and dikes and sills. These rocks are all of monzonitic composition, though differing somewhat from point to point. Numerous similar dikes lie farther south in the Stockton district, in Dry Canyon and in the "Birdseye" porphyry of Lion Hill and the Mercur district.

Dikes and sills in the southern part of the range in the Mercur and Ophir districts are fine grained and rather highly altered. Their composition is not definitely determined, but apparently they are considerably more siliceous than the other rocks. The dome structure centering at Ophir strongly suggests an underlying body of intrusive rock.

The similarity in composition of the rocks in the northern part of the area leaves little doubt that they are from a common source and were intruded at essentially the same time. The siliceous rocks at the southern end of the range are not so certainly of the same age and origin, but no known evidence shows that they are of different age, and their composition may well have resulted from differentiation of a single magma.

The relation of the intrusive to the extrusive rocks is nowhere clear, though the intrusives have been generally considered to be the older. In the Tintic district, to the south, the two are of essentially the same age, and it seems quite probable that the same may be true of the Oquirrh Range.

There is no evidence of the geologic age of the intrusive rocks further than that they are younger than the Carboniferous rocks, which they cut, and older than the lake sediments. Comparison with other districts of the State suggests that they are of Tertiary age.

STRUCTURE.

Both folding and faulting are important in the Oquirrh Range. All the faulting seems later than the folding, and the latest faulting is believed to have been an important factor in outlining the range.

FOLDING.

The range is composed of a series of broad open folds trending and pitching generally northwest. In the southern part these folds are very regular, and where cut by deep canyons expose almost diagrammatic sections. The southern part of the range consists of an anticline on the west and a syncline on the east, both cut off by the western front of the range south of Tooele Canyon. The northern part of the range apparently has a similar general structure but is much more complicated by faulting.

At Ophir the western anticline has been raised into a dome or quaquaversal, giving the anticline a gentle southerly pitch and a rather pronounced northerly pitch, which to the north exposes successively younger beds, ranging from Lower Cambrian to upper Carboniferous or Pennsylvanian.

FAULTING.

The general north-south trend of the range is most readily explained as being due to a strong fault which truncated the folds along the western front. Recent movement is known to have taken place on a fault line extending along this front with relative uplift to the east.[1]

East-west faulting has also exerted an important influence on the large structural features of the district. In Ophir Canyon an east-west fault is associated with the dome structure, with whose formation it was probably associated.

Emmons[2] has called attention to an east-west zone of faulting just south of Butterfield Canyon and to a second east-west fault north of Bingham Canyon that follows the general direction of Dry Canyon and that has thrown the Bingham quartzite down against the underlying limestones. Concerning the influence of the faults Emmons says that

> It appears that the sedimentary rocks of the Bingham area at present occupy an abnormally depressed position relative to the portions of the range lying to the north and to the south of it, and that with respect to the northern portion, at least, this relation has evidently been brought about by faulting. * * *
>
> In the northern third of the range, between Connor Peak and Salt Lake, as contrasted with the south half, east-west to north trends characterize the master structure lines, and faulting is more prominent than folding. Evidence of this is seen on the steep northern face of the range that fronts toward Salt Lake, which apparently represents a fault scarp with a trend a little north of east. The sedimentary beds on this face, largely limestones, dip from 60° N. to vertical, while small outliers in the lake beyond—Sheep and Black rocks—have southerly dips.

Detailed mapping of the range will doubtless reveal other large faults. Minor faults are numerous and many of them are important on account of their association with the ore deposits.

A fissuring of the rocks, possibly accompanied by slight movement, has had no important influence on the large structural features of the range but has been of large importance in connection with the deposition of ores. These ore-bearing fissures vary in direction from place to place, but throughout the range most of the important ones trend generally north. Barren fissures extend in every direction, especially in the Bingham district.

ORE DEPOSITS.

CHARACTER AND DISTRIBUTION.

The ore deposits of the several districts in the Oquirrh Range show rather marked differences when considered individually, but when viewed as a whole are sufficiently similar to indicate that they are closely related—that they probably derived their metal content from the same source and are of essentially the same age.

In character the ores of the Bingham district are the most varied in the range. They occur as disseminated deposits in altered monzonite and quartzite adjacent to the monzonite; as vein deposits in the monzonite and in the

[1] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, p. 352, 1890.

[2] Emmons, S. F., General geology of the Bingham mining district, Utah: U. S. Geol. Survey Prof. Paper 38, p. 22, 1905.

sedimentary rocks; and as replacement, fissure, and bed deposits in the limestone.

The disseminated deposits are typically copper; the replacement veins are lead-silver deposits, but many of them carry important amounts of copper and zinc. The replacement deposits in the limestone are both copper and lead-silver or lead-silver-zinc. Some deposits contain relatively small amounts of the baser metals and are essentially siliceous silver ores. All the ores carry some precious metal. The ores of the Stockton district are essentially lead-silver but contain some zinc and copper. The ores of Dry Canyon are mainly lead-silver and zinc but contain some copper. Some of them were chiefly valuable for silver. The Ophir district, like Dry Canyon, is mainly lead-silver but also yields zinc and copper. The Lion Hill area is typically a silver-producing district, but it also yields lead and small amounts of zinc and copper. The Mercur, West Dip, and Sunshine camps are chiefly gold producers, though the Mercur district has yielded some silver.

Thus, the Bingham district at the north is the only one containing valuable bodies of copper ore, and the districts in the extreme south of the range are noted principally for their precious metals. The intervening districts produce chiefly lead and silver but yield also a considerable amount of copper and zinc.

GEOLOGIC RELATIONS.

The character of the ore deposits bears a general relation to the igneous rocks of the range. In the Bingham district the important copper deposits lie either in or close to the large intrusive bodies and the lead-silver and zinc deposits in the limestones some distance away. There are gradations between the copper and lead-silver deposits. Lead-silver-zinc deposits occur in the intrusive rocks but are believed to be slightly younger than the copper deposits, which in places are cut by veins carrying lead, silver, and zinc.

In the Stockton, Dry Canyon, and Ophir districts only small dikes of intrusive rock are present, and the ore deposits associated with them are characterized by lead, silver, and zinc and by minor amounts of copper.

In the districts in the south end of the range only relatively small bodies of siliceous igneous rock are present, and the associated deposits are characterized by precious metals and by a scarcity of base metals.

A further relation between the igneous rocks and the characters of the different deposits is indicated by certain of the ore and gangue minerals, which form within certain temperature ranges. The gangue minerals characteristically associated with the copper deposits, including biotite in the altered porphyry and garnet and other contact silicates in the limestones, are those that form at relatively high temperatures. The minerals associated with the lead-zinc ores are those that form at lower temperatures, being mainly quartz, some sericite, and a little garnet and tremolite. No minerals typical of high-temperature conditions were found in the precious-metal deposits toward the southern end of the range, but cinnabar, realgar, and minerals common to moderate temperatures are present.

From the above relations it may be considered that the ores are derived from a common source and that their distribution is due to varying conditions of temperature and pressure. Copper has been deposited under conditions of greatest heat and pressure, lead and zinc as these decreased, and precious metals and mercury and arsenic at the lower limits of deposition and at the greatest distance from the source. The presence of lead-zinc deposits in the monzonite body can be explained by assuming that the deposition continued over a considerable period and that they were deposited later than the copper and after the temperature had been reduced. Other conditions were probably factors in the deposition of the gold and silver deposits. (See p. 394.)

Ore has been deposited at many horizons, from Lower Cambrian to upper Carboniferous. The Ophir Hill deposits are in the Cambrian; the Lion Hill, Mercur, and Dry Canyon deposits in the lower Carboniferous, and the Stockton and Bingham deposits in the upper Carboniferous. The age of the sediments, therefore, does not appear to determine their importance as ore carriers.

The composition of the sedimentary rocks, on the other hand, does appear to be an important and perhaps a controlling factor. The lead-zinc ores most readily replace the purer limestones or dolomites, and only in small degree the siliceous sediments, and the gold deposits are closely associated with shaly beds,

commonly containing carbonaceous matter, whose composition has probably helped to precipitate the gold.

Structurally, the deposits of the range have a general similarity, though individual deposits differ greatly in detail. Most of the deposits in the sedimentary rocks are associated with north-south fissures and have formed as replacements of certain beds in chimneys or shoots following the intersection of the ore fissure and the replaced bedding.

MINERALOGY.

The mineralogy of the several deposits and the alteration by surface agencies can best be discussed in connection with the description of the individual districts.

BINGHAM OR WEST MOUNTAIN DISTRICT.

INTRODUCTION.

The following description of the Bingham district is based very largely on the work of Boutwell, Keith, and Emmons,[1] published in 1905. The writer, however, with G. F. Loughlin, spent several days in the district in August, 1912, collecting data on the disseminated deposits (which had been only slightly developed at the time of Boutwell, Keith, and Emmons's study of the district) and visiting most of the larger mines though attempting no detailed study of them. Free use has also been made of a paper by Beeson,[2] dealing particularly with the disseminated deposits of the district. Atwood[3] has also contributed to the study of the physiography of the range.

LOCATION.

The Bingham (West Mountain) mining district is on the eastern slope of the Oquirrh Range, about 20 miles southwest of Salt Lake City. The greater part of the mineralized area lies in Bingham Canyon and in canyons tributary, though some ore bodies are in canyons to the east, south, and west.

[1] Economic geology of the Bingham mining district, Utah: U. S. Geol. Survey Prof. Paper 38, 1905.

[2] Beeson, J. J., The disseminated copper ores of Bingham, Utah: Am. Inst. Min. Eng. Bull. 107, pp. 2191-2220, Nov., 1915.

[3] Atwood, W. W., The physiographic conditions at Butte, Mont., and Bingham Canyon, Utah, when the copper ores in these districts were enriched: Econ. Geology, vol. 11, pp. 697-740, 1916.

HISTORY AND PRODUCTION.

By V. C. Heikes.

HISTORY.

The first discovery of mineral in the camp is said to have been made by G. B. Ogilvie in the fall of 1863; and the first claim, the West-Jordan, was formally located by the discoverer and others. The district was organized as the West Mountain district, December 17, 1863. The first location was followed by others and by some development. Conditions, however, were unfavorable, owing to the lack of transportation facilities and of suitable reduction plants, and active production from the lodes did not begin till some years later.

In 1864 placer gold was found in the gravels of Bingham Canyon. Production began in the spring of 1865 and during the next six years totaled about $1,000,000. After 1871 the importance of the placers declined, but they have produced intermittently till recent years and have yielded a total of nearly $1,500,000.

The Union and Central Pacific railroads, which were completed in 1869 and were soon connected with Salt Lake City by the Utah Central, greatly improved transportation facilities, and in 1873 a railroad was opened from Salt Lake City to Bingham Canyon. These improved conditions stimulated lode mining. The first shipment of ore is said to have been a carload of copper ore shipped by Walker Bros. to Baltimore in 1868. Lead-silver ores, however, furnished the main production for some years.

In the early days only oxidized ores could be successfully treated and when the sulphide zone was reached the output of lead and silver declined. In the late seventies several mills were constructed to recover the gold from the gossan or oxidized portion of the ore bodies in limestone, but the output from this type of ore has not been large as compared with other types.

In 1881 new deposits of lead were discovered in Butterfield Canyon and these, with the output from the older portion of the district, produced considerable lead and silver till the fall in price of silver in 1893 dealt a severe blow to the business.

The production of copper from Bingham on an important scale began in 1896, the first

large output being from the Highland Boy mine. The success of this mine stimulated prospecting, and soon an important output was being made from the low-grade sulphide deposits in the limestones.

Prospecting of the disseminated ores of the district was carried on from the time that copper became an important factor in the output of the camp, but it was several years before important production was made from this type of ore. About 1904 systematic development by churn drill and underground methods was begun by several companies, large bodies of ore were rapidly proved, and a small output from experimental mills was soon made. Extensive production, however, did not begin until the completion of the large concentrating plants of the Utah Copper Co. and the Boston Consolidated Copper Co. at Garfield, and of the Ohio Copper Co. at Lark. The mill of the Utah Copper Co. began operation in 1907, that of the Boston Consolidated in 1908, and that of the Ohio Copper Co. in 1909. The Utah Copper Co. had previously operated a 500-ton experimental mill in Bingham Canyon.

At the present time, through consolidation, a large part of the ground known to contain important bodies of disseminated copper ore is held by the Utah Copper Co., the Ohio Copper Co. being the only other important operator.

MINING METHODS.

The strong relief in the district is favorable to the opening of ore bodies by tunnels, and these have been very generally used since the early days of mining. In the lower areas, notably in the eastern part of the district, where depth could not be readily attained by tunnels, shafts were sunk, and in recent years these have been used in other parts of the district to develop the ore bodies to greater depth than has been found feasible by tunneling. For the most part, however, as greater depth has been desired, long drain tunnels have been driven, as the 14,000-foot Mascotte tunnel from the east side of the range to intersect the ore body in the Ohio Copper Co.'s ground, and the 11,000-foot Utah Metal Mining Co.'s tunnel from the west or Tooele side of the range to upper Carr Fork.

The early development of the disseminated deposits was mainly by tunnel and, to a slight extent, by shafts. Later churn drills were brought into use, and a large percentage of the ore has been systematically developed by this method at a relatively low cost.

Methods of extraction of the ores have differed with the character of the deposit and have changed as more economical methods have been developed. In the replacement veins the prevailing method in the early days was the square set and fill, and in many deposits this relatively costly method of extraction is still found necessary. In the smaller veins only stulls are required to hold the walls. More recently various modifications of the top slicing and caving systems have been successfully employed in extracting the larger sulphide ore bodies. In the disseminated ore bodies the underground extraction has been principally by the systems of caving and shrinkage stopes. For a large part of this type of deposits it has been found more economical to strip the overburden and remove the ore by open-cut methods. In this method the rock is shattered by heavy blasts and then handled by steam shovels. Since 1914 the Utah Copper Co. has mined practically all its disseminated ore by this method.

REDUCTION.

In the early days of mining in the district, when the oxidized lead-silver ores constituted the main output, treatment of the ores was relatively simple. Several blast furnaces, constructed in and near the district, made good saving of metals, though the high cost of operation made it possible to treat only the relatively high-grade ores.

Numerous attempts to treat the gold ores in the upper portion of many of the ore bodies were only indifferently successful. Several stamp mills were built and operated for short periods, the gold being recovered by amalgamation. Later at the Highland Boy mine cyanidation was tried but without satisfactory results. Considerable gold was recovered in the several mills, but it is doubtful if the metal recovered paid the costs of operation. Leaching of the siliceous ores of the Telegraph mine was early attempted, and in 1910 a 50-ton cyanide plant was built by the Utah Leasing Co. for this mine. The discovery of extensive bodies of copper sulphide ores led to the construction in the valley south of Salt Lake of smelters, which were operated successfully until 1907, when they were closed by order of the courts because of damage to vegetation. A copper-smelting

plant that had been operated in Bingham Canyon by the Yampa Copper Co. for several years was closed in 1910.

At present the copper ores of the district are treated mainly at the plant of the Garfield Smelting Co. at Garfield, and that of the International smelter at International, on the west side of the Oquirrh Range. The Garfield smelter, completed in 1906, is especially adapted to the treatment of the concentrates of the district but is also equipped with blast furnaces for the treatment of direct-smelting ores. The International plant, when blown in in 1910, was equipped for the treatment of copper ore and concentrates, and later equipment for the treatment of lead ores was added. The lead ores and concentrates of the district are treated at the International smelter, at the plant of the United States Mining, Smelting & Refining Co. at Midvale, and at that of the American Smelting & Refining Co. at Murray.

Numerous mills have been and still are operated for the concentration of the low-grade lead-silver ores. The zinc content of most ores has been low enough to be kept, by judicious mixing, below the percentage allowed by the smelters without penalty.

The United States Mining, Smelting & Refining Co. has installed Huff electrostatic machines for treating zinc middlings from the ores from its Bingham mines and has made a considerable production of zinc. The zinc concentrates are shipped to eastern plants for further treatment. In 1915 the American Smelting & Refining Co. built an experimental plant at Murray for the production of electrolytic zinc.

Since 1907 the low-grade disseminated copper ores of the district have been treated in three large mills—the Magna mill of the Utah Copper Co. near Garfield, with a daily capacity of about 18,000 tons of ore; the Arthur mill (originally Boston Consolidated) of the same company, with a capacity of about 15,000 tons, and the mill of the Ohio Copper Co. at Lark, with a capacity, when completed, of about 5,000 tons. With these mills operating at capacity, about 38,000 tons of ore can be treated daily, but this can be greatly exceeded at the sacrifice of metal recovered. In 1917 the Magna and Arthur mills treated an average of more than 34,000 tons of ore daily.

METAL CONTENT OF THE ORES.

DRY OR SILICEOUS ORE.

The dry or siliceous ores shipped to smelters from the Bingham (West Mountain) district comprise gold and silver ores carrying small quantities of the sulphide minerals of copper and lead. Such ores have been used at the smelters principally for converter lining. Silver bullion containing a little gold was treated at a cyanide mill in the district, but the tonnage does not enter into the averages given below and can not be given separately without disclosing individual production. The shipping grade of dry or siliceous ore was produced from the Old Jordan, Mystic Shrine, Story, Utah Apex, Parnall, Sampson, Buffalo, Niagara, Gold & Silver, Utah Bingham, and Queen.

The average grade of the ores from the aggregate yield of these mines is as follows:

Siliceous ore, with average metallic content, produced in the Bingham (West Mountain) district and shipped to smelters, 1903–1917.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
1903.....	1,848	$0.93	2.23	0.24	....	$2.81
1904.....	1,918	6.44	10.35	1.40	0.34	16.32
1905.....	2,643	3.54	5.30	1.39	....	11.10
1908.....	2,412	5.27	18.43	....	.03	15.06
1909.....	8,102	3.40	11.69	.20	.37	10.31
1910.....	7,808	3.01	11.49	.85	1.55	12.75
1911.....	1,071	8.14	7.00	1.39	2.10	17.22
1912.....	1,432	7.03	5.03	.98	.04	13.40
1913.....	718	7.70	6.73	1.03	1.22	16.04
1914.....	820	5.82	4.33	.79	.10	10.39
1915.....	498	4.79	6.94	.79	.08	11.06
1916.....	110	2.58	4.65	1.21	....	11.60
1917.....	425	1.07	4.35	.76	.05	8.94

COPPER ORE AND CONCENTRATES.

Copper ores of two grades were shipped from the district, the bulk going to the concentration mills at Garfield and a fluxing grade directly to the smelters. They include ores carrying over 2½ per cent of copper, or even less in the case of the great disseminated copper deposit at Bingham. The copper ore shipped directly to the smelters came from the following properties, named in the order of their frequency as regular shippers: Highland Boy (Utah Consolidated), Yampa, Old Jordan, Commercial, Bingham, New Haven, Boston Consolidated, Columbia (Ohio Copper), Utah Apex, Utah Copper, Fortuna, Dalton & Lark,

Mystic Shrine, Bingham Consolidated, Butler Liberal, Copper Glance, New Red Wing, Story, Brooklyn, New England, Niagara, Valentine Script, Bingham Mary, Lone Pine, Pine Tree, Bingham Mines, Ute Copper, Yosemite, Winnamuck, Colorado & Maple, and Gold & Silver. The copper concentrates, as sulphides, were produced during the last decade from the Utah Copper, Columbia (Ohio Copper), Boston Consolidated, and Eddie.

The average grade of the ore and concentrates representing the aggregate yield of the district is shown in the following table:

Copper ore and concentrates, with average metallic content, produced in the Bingham (West Mountain) district and shipped to smelters, 1903–1917.

Crude ore.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
1903...	427,844	$2.06	1.96	2.15	....	$9.03
1904...	552,761	2.01	2.28	2.30	....	9.23
1905...	648,896	1.86	2.12	2.30	....	10.34
1906...	639,355	2.34	1.98	2.46	....	13.19
1907...	717,704	1.78	1.58	2.00	....	10.81
1908...	512,755	1.57	1.06	2.07	....	7.61
1909...	593,523	1.49	1.14	1.99	....	7.25
1910...	472,511	1.64	1.55	2.25	....	8.26
1911...	567,941	1.96	1.78	2.15	....	8.29
1912...	424,471	1.93	1.77	1.64	....	8.43
1913...	493,833	1.65	1.47	1.71	....	7.85
1914...	407,587	2.40	1.79	1.74	....	8.03
1915...	393,374	1.96	2.06	2.09	....	10.35
1916...	576,010	1.63	1.62	1.87	....	11.88
1917...	442,720	1.46	1.50	1.86	....	12.91
Concentrates.						
1904...	9,215	$2.85	1.28	25.90	....	$69.89
1905...	15,364	2.94	1.16	27.22	....	88.57
1906...	14,963	2.61	.98	22.86	....	91.52
1907...	29,799	3.87	1.73	26.56	....	111.24
1908...	99,164	3.18	1.38	22.12	....	62.32
1909...	143,517	3.38	1.55	23.45	....	65.17
1910...	176,279	4.75	2.18	25.84	....	71.56
1911...	207,472	4.08	1.93	24.70	....	66.88
1912...	250,420	2.99	1.33	20.08	....	70.07
1913...	373,691	1.62	.83	16.65	....	53.75
1914...	355,152	2.07	.99	17.56	....	49.33
1915...	427,241	1.83	.96	18.29	....	66.35
1916...	555,557	1.74	.86	17.87	....	90.23
1917...	649,609	1.59	.79	15.83	....	88.70

LEAD ORE AND CONCENTRATES.

In general the crude lead ore and concentrates are those containing over 4½ per cent of lead. The bulk of the lead ore, carrying low contents of lead and zinc, is shipped to Midvale, Utah, for concentration and separation. A good average grade of lead ore is shipped directly to the smelters from the following properties, named in the order of their frequency as shippers during the last decade: Bingham New Haven, New England, Dalton & Lark, Utah Apex, Silver Shield, Niagara, Sampson, Highland Boy (Utah Consolidated), Old Jordan, Queen, Montezuma, Utah Bingham, Story, Commercial, Butler Liberal, Fortuna, Yosemite, Utah Copper, New Red Wing, Phoenix, Massasoit, Winnamuck, Last Chance, Central Standard, North Utah, Yampa, Bingham Consolidated, Cluster, Mystic Shrine, United Bingham, Bingham-Butte, Conglomerate, Ute Copper, Petro, Green Grove, Ivanhoe, Bingham Group, Boston Consolidated, Greely, Utah Metal, Bingham Mines, Montana Bingham, Brooklyn, Julia Dean, and St. James.

The average grade of the ore and concentrates representing the aggregate yield of the district is shown in the following table:

Lead ore and concentrates, with average metallic content, produced in the Bingham (West Mountain) district and shipped to smelters, 1903–1917.

Crude ore.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
1903.....	6,047	$2.25	8.91	0.38	8.78	$15.48
1904.....	13,134	.87	11.77	1.35	19.32	27.79
1905.....	53,340	.92	9.98	.85	19.23	27.73
1906.....	74,041	1.23	8.36	.73	14.35	26.10
1907.....	47,355	2.37	8.27	.72	16.18	27.88
1908.....	25,035	2.83	8.57	1.49	19.90	28.03
1909.....	24,443	1.27	10.78	1.35	22.76	29.97
1910.....	16,353	1.41	11.80	.57	22.85	29.34
1911.....	91,818	1.60	9.46	.80	16.12	23.12
1912.....	76,764	1.16	6.23	.76	16.86	22.67
1913.....	161,067	1.16	5.11	.74	14.39	19.20
1914.....	123,723	1.20	5.47	.68	17.34	19.56
1915.....	146,067	3.80	5.78	.70	15.94	24.19
1916.....	158,518	1.06	5.66	.70	14.65	28.49
1917.......	142,564	.94	5.66	.66	13.65	32.70
Concentrates.						
1904.....	300	$4.75	10.00	....	19.27	$27.13
1905.....	853	.75	14.63	....	19.38	27.90
1906.....	3,143	1.72	9.20	0.11	26.77	38.90
1907.....	20,316	2.91	9.98	.50	16.09	28.46
1908.....	13,859	1.82	7.09	.76	18.48	23.11
1909.....	51,968	1.78	6.82	.91	18.45	23.56
1910.....	56,714	1.72	6.86	.52	19.84	24.21
1911.....	58,791	1.80	6.09	.56	14.17	19.18
1912.....	54,152	1.89	7.18	.83	16.44	23.84
1913.....	65,128	2.10	7.45	.85	18.77	25.74
1914.....	75,321	3.70	8.26	.85	22.26	27.90
1915.....	89,962	4.44	7.05	.93	18.57	28.75
1916.....	110,409	3.74	7.10	.58	17.37	35.23
1917.....	87,600	4.86	8.95	.65	19.20	48.81

The properties producing lead ores of milling grade concentrated at Bingham and Midvale were the New England, Utah Apex, Old Jordan, Telegraph and Galena (United States), Bingham New Haven, Butler Liberal, Phoenix, Silver Shield, New Red Wing, Last Chance, North Utah, Commercial, Massasoit, Yampa, Utah Copper, Winnamuck, Eagle Bird, Mystic Shrine, Central Standard, Shawmut, Montezuma, Bingham Mines, Highland Boy, Ute Copper, Brooklyn, Cluster, Dalton & Lark, Queen, Ivanhoe, Niagara, and Utah Metal.

COPPER-LEAD ORE.

The copper-lead ores are classified according to the same method as the copper and lead ores. The producers of this kind of ore were the Sampson, Fortuna, Last Chance, and Summit. The average grade of the ore shipped is shown in the following table:

Copper-lead ore, with average metallic content, produced in the Bingham (West Mountain) district and shipped to smelters, 1907–1913, 1916.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
1907......	564	$0.79	12.80	3.30	12.72	$36.27
1908......	189	.36	13.25	3.64	20.00	33.81
1911......	187	6.42	9.83	18.85	18.44	75.36
1912......	15	24.67	22.67	3.32	12.25	60.63
1913......	16	2.25	46.81	5.78	9.52	56.87
1916......	272	15.29	9.96	3.89	4.90	47.77

LEAD-ZINC ORE.

Crude lead-zinc ore was shipped from the Ute Copper (Winnamuck), Bingham, Orleans, and Jumbo properties. The average of the ores shipped follows:

Lead-zinc ore, with metallic content, produced in the Bingham (West Mountain) district and shipped to smelters, 1910–11, 1916–17.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).
1910........	101	$1.24	8.36	0.30
1911........	835	1.55	6.79	.24
1916........	6,930	....	....	....
1917........	3,006	....	....	....

Lead-zinc ore, with metallic content, produced in the Bingham (West Mountain) district and shipped to smelters, 1910–11, 1916–17—Continued.

Year.	Lead (per cent).	Recoverable zinc (per cent).	Average gross value per ton.
1910..................	9.24	25.20	$41.89
1911..................	11.36	9.28	26.56
1916..................	8.19	12.46	44.71
1917..................	11.54	10.11	40.49

ZINC CONCENTRATES.

Zinc concentrates, recovered from ores treated largely at Midvale in the concentrating plant of the United States Mining Co., came from the Old Jordan (United States), Dalton & Lark, Utah Copper, Commercial, Last Chance, Silver Shield, Cluster, New England, Ivanhoe, Massasoit, Butler Liberal, Niagara, Utah Apex, Utah Metal, and Winnamuck. The average grade of the concentrates is shown in the following table:

Zinc concentrates, with metallic content, produced in the Bingham (West Mountain) district and shipped to smelters, 1909–1913, 1915–1917.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).
1909........	1,000	....	....	....
1910........	4,548	....	....	....
1911........	5,669	....	....	....
1912........	3,041	$0.74	3.72	0.75
1913........	4,821	.49	1.96	.55
1915........	6,550	....	....	....
1916........	10,590	....	....	....
1917........	5,874	....	....	....

Year.	Lead (per cent).	Recoverable zinc (per cent).	Average gross value per ton.
1909..................	....	32.48	$35.07
1910..................	....	38.71	41.81
1911..................	....	40.22	45.85
1912..................	2.17	44.59	69.01
1913..................	1.75	35.49	44.71
1915..................	....	41.92	103.95
1916..................	....	40.82	109.40
1917..................	....	34.01	80.38

PRODUCTION.

The following table gives the yearly output of metals from the beginning of operations to the close of 1917:

Quantity of ore sold or treated in Bingham (West Mountain) district, 1865–1917, and total metals recovered.

Year.	Ore, short tons.	Gold.		Silver.		Copper.		Lead.		Recoverable zinc.		Total value.[a]
		Fine ounces.	Value.	Fine ounces.	Value.	Pounds.	Value.	Pounds.	Value.	Pounds.	Value.	
1865... 1873[b]..	....	43, 506.00	$899, 340	1, 207, 212	$1, 583, 910	90, 500	$25, 311	13, 958, 000	$862, 192	....	....	$3, 370, 753
1874...	....	[c]4, 111.00	84, 982	[d]416, 920	533, 658	[d]120, 000	26, 400	[e]4, 000, 000	240, 000	....	....	885, 040
1875...	....	[c]1, 451.00	29, 995	[d]300, 000	372, 000	[d]400, 000	90, 800	[e]27, 000, 000	1, 566, 000	....	....	2, 058, 795
1876...	....	[d]1, 800.00	37, 209	[d]435, 000	504, 600	[d]536, 000	112, 560	[f]26, 000, 000	1, 586, 000	....	....	2, 240, 369
1877...	....	[g]3, 750.00	77, 519	[d]550, 000	660, 000	[d]228, 000	43, 320	[f]21, 000, 000	1, 155, 000	....	....	1, 935, 839
1878...	....	[g]3, 000.00	62, 016	[d]650, 000	747, 500	[d]534, 400	88, 710	[d]15, 070, 000	542, 520	....	....	1, 440, 746
1879...	....	[g]4, 000.00	82, 687	[h]950, 000	1, 064, 000	[d]100, 000	18, 600	[d]8, 460, 000	346, 860	....	....	1, 512, 147
1880...	....	[g]7, 410.00	153, 178	[d]430, 965	495, 610	[d]50, 000	10, 700	[d]8, 942, 704	447, 135	....	....	1, 106, 623
1881...	....	[g]4, 317.00	89, 240	[d]805, 193	909, 868	[d]45, 000	8, 100	[d]12, 345, 700	592, 594	....	....	1, 599, 892
1882...	....	[c]3, 386.00	69, 995	[c]433, 134	493, 773	[d]50, 080	9, 565	[d]8, 500, 000	416, 500	....	....	989, 833
1883...	....	[c]3, 173.00	65, 592	[c]439, 981	488, 379	[d]50, 000	8, 250	[d]16, 250, 000	698, 750	....	....	1, 260, 971
1884...	[d]24, 787	[c]5, 000.00	103, 359	[d]440, 590	489, 059	[d]95, 000	12, 350	[i]15, 350, 000	567, 950	....	....	1, 172, 718
1885...	....	[c]5, 000.00	103, 359	[c]1, 350, 000	1, 444, 500	[d]100, 000	10, 800	[d]14, 250, 000	555, 750	....	....	2, 114, 409
1886...	....	[c]5, 000.00	103, 359	[c]800, 000	792, 000	[d]240, 000	26, 640	[d]20, 000, 000	920, 000	....	....	1, 841, 999
1887...	....	[c]4, 400.00	90, 956	[c]600, 000	588, 000	[d]500, 000	69, 000	[d]18, 000, 000	810, 000	....	....	1, 557, 956
1888...	....	[c]3, 500.00	72, 351	[c]483, 000	454, 020	[d]650, 000	109, 200	[d]18, 000, 000	792, 000	....	....	1, 427, 571
1889...	....	[c]4, 705.00	97, 261	[c]561, 280	527, 603	[d]250, 700	33, 845	[d]17, 588, 000	685, 932	....	....	1, 344, 641
1890...	....	[c]4, 037.00	83, 452	[c]450, 990	473, 540	[d]175, 000	27, 300	[d]17, 202, 000	774, 090	....	....	1, 358, 382
1891...	....	[c]6, 564.00	135, 690	[c]750, 500	742, 995	[d]594, 618	76, 111	[d]26, 563, 000	1, 142, 209	....	....	2, 097, 005
1892...	....	[c]4, 644.00	96, 000	[c]605, 896	527, 130	[d]497, 000	57, 652	[d]24, 505, 500	980, 220	....	....	1, 661, 002
1893...	....	[c]8, 000.00	165, 375	[c]650, 000	507, 000	[d]205, 000	22, 140	[d]20, 042, 100	741, 558	....	....	1, 436, 073
1894...	....	[c]11, 000.00	227, 390	[c]650, 000	409, 500	[d]274, 756	26, 102	[d]14, 250, 000	470, 250	....	....	1, 133, 242
1895...	....	[c]10, 000.00	206, 718	[c]700, 000	455, 000	[d]610, 708	65, 346	[d]15, 842, 300	506, 954	....	....	1, 234, 018
1896...	....	[c]8, 000.00	165, 375	[c]610, 000	414, 800	[d]500, 000	54, 000	[d]15, 542, 312	466, 269	....	....	1, 100, 444
1897...	....	[c]7, 200.00	148, 837	[c]500, 000	300, 000	[d]1, 419, 010	170, 281	[d]11, 456, 782	412, 444	....	....	1, 031, 562
1898...	....	[c]9, 000.00	186, 047	[c]350, 000	206, 500	[d]2, 283, 791	283, 190	[d]5, 720, 000	217, 360	....	....	893, 097
1899...	....	[c]8, 611.00	178, 005	[c]201, 801	121, 081	[c j]4, 145, 028	708, 800	[c]2, 320, 000	104, 400	....	....	1, 112, 286
1900...	[d]101, 132	[c]12, 226.00	252, 734	[c]238, 267	147, 726	[c]6, 196, 660	1, 028, 646	[c]4, 260, 000	187, 440	....	....	1, 616, 546
1901...	....	[d]17, 262.00	356, 837	[d]691, 923	415, 154	[d]14, 422, 361	2, 408, 534	[d]2, 754, 779	118, 455	....	....	3, 298, 980

[a] Average commercial prices used for each metal to make total for each calendar year.
[b] In 1864 placers discovered and in 1865 gravel washing actively taken up. Estimated up to 1871 about $1,000,000 in gold produced, but only known production included in table. First shipment of ore in Utah was a carload of copper ore from Bingham in June, 1868. See U. S. Geol. Survey Prof. Paper 38, p. 83, 1905.
[c] U. S. Geol. Survey Prof. Paper 38, p. 97, 1905.
[d] Estimated by V. C. Heikes from a separation of the total output reported by the Director of the Mint or given in the annual reviews of the Salt Lake Tribune and U. S. Geol. Survey Mineral Resources, 1882–1897. Part of the records of some early producers were used in the estimates.
[e] Winnemuck mine largest producer of lead ores starts heavy output in 1872.
[f] Old Telegraph mine principal producer.
[g] Salt Lake Tribune, Jan. 1, 1878.
[h] U. S. Geol. Survey Sixteenth Ann. Rept., pt. 2, pp. 354–357, 1894–95.
[i] U. S. Geol. Survey Mineral Resources, p. 417, 1884.
[j] Highland Boy mine starts with heavy output.

Quantity of ore sold or treated in Bingham (West Mountain) district, 1865–1917, and total metals recovered—Continued.

Year.	Ore, short tons.	Gold.		Silver.		Copper.		Lead.		Recoverable zinc.		Total value.[a]
		Fine ounces.	Value.	Fine ounces.	Value.	Pounds.	Value.	Pounds.	Value.	Pounds.	Value.	
1902...	260, 790	[a]26, 580.00	549, 457	[a]477, 883	253, 278	[a]14, 759, 621	1, 815, 433	[a]3, 896, 436	159, 754	....	....	2, 777, 922
1903...	433, 759	[a]43, 192.00	892, 858	[a]880, 129	475, 270	[a]17, 279, 804	2, 367, 333	[a]2, 241, 283	94, 134	....	....	3, 829, 595
1904...	705, 792	[a]56, 391.00	1, 165, 685	[a]1, 448, 360	829, 476	[a][b]30,628,834	3, 828, 604	[a]5, 204, 383	227, 702	....	....	6, 051, 467
1905...	[a]1, 012, 009	[a]63, 701.00	1, 316, 817	[a]1, 980, 583	1, 196, 272	[a]39, 219, 734	6, 118, 279	[a]23, 494, 879	1, 104, 250	....	....	9, 735, 627
1906...	[a]996, 121	[a]78, 986.03	1, 632, 786	[a]1, 927, 350	1, 291, 325	[a]39, 424, 276	7, 608, 885	[a]22, 927, 661	1, 306, 877	....	....	11, 839, 873
1907...	[a]1, 503, 082	[a]75, 730. 24	1, 565, 483	[a]1, 786, 580	1, 179, 143	[a]45, 431, 964	9, 086, 393	[a]21, 971, 064	1, 164, 466	....	....	12, 995, 485
1908...	[a]2, 691, 640	[a]60, 382.69	1, 248, 221	[a]1, 053, 146	558, 168	[a]71, 155, 740	9, 392, 558	[a]15, 169, 518	637, 120	....	....	11, 836, 067
1909...	[a]4, 166, 992	[a]73, 599.47	1, 521, 436	[a]1, 615, 394	840, 005	[a]92, 560, 340	12, 032, 844	[a]30, 365, 819	1, 305, 730	649, 542	$35, 075	15, 735, 090
1910...	[a]5, 427, 953	[a]85, 526.61	1, 767, 992	[a]1, 800, 410	972, 222	[a]113, 725, 280	14, 443, 110	[a]30, 271, 016	1, 331, 925	3, 572, 347	192, 907	18, 708, 156
1911...	[a]6, 044, 893	[a]110, 389.00	2, 281, 943	[a]2, 786, 810	1, 477, 009	[a]129, 995, 865	16, 249, 483	[a]46, 576, 337	2, 095, 935	4, 715, 121	268, 762	22, 373, 132
1912...	[a]6, 567, 948	[a]86, 375.11	1, 785, 532	[a]2, 028, 496	1, 247, 525	[a]116, 621, 793	19, 242, 596	[a]43, 822, 495	1, 972, 012	2, 711, 982	187, 127	24, 434, 702
1913...	[a]9, 190, 374	[a]85, 856.66	1, 774, 815	[a]2, 408, 692	1, 454, 850	[a]144, 920, 494	22, 462, 676	[a]71, 001, 138	3, 124, 050	3, 421, 724	191, 616	29, 008, 007
1914...	7, 800, 661	[a]104, 079.80	2, 151, 520	2, 383, 051	1, 317, 827	141, 924, 811	18, 876, 000	76, 453, 128	2, 981, 672	4, 121, 977	210, 221	25, 537, 240
1915...	9, 693, 184	[a]121, 299.19	2, 507, 477	2, 704, 833	1, 371, 351	176, 593, 414	30, 903, 848	80, 004, 006	3, 760, 188	5, 491, 359	680, 929	39, 223, 793
1916...	12, 777, 683	[a]120, 461.39	2, 490, 158	3, 095, 335	2, 036, 730	223, 619, 609	55, 010, 424	85, 996, 490	5, 933, 758	10, 765, 192	1, 442, 536	66, 913, 606
1917...	14, 350, 394	[a]108, 415.71	2, 241, 152	2, 786, 120	2, 295, 763	225, 411, 675	61, 537, 387	73, 523, 708	6, 323, 039	4, 608, 474	469, 554	72, 866, 895
Total[c].	....	1, 515, 018.90	31, 318, 190	48, 415, 824	35, 665, 120	1,658,636,866	296, 608, 196	1,058,092,538	52, 429, 453	40, 052, 718	3, 678, 727	419, 699, 686

a U. S. Geol. Survey Mineral Resources, 1902–1917.
b Utah Copper Co. begins production in 1904.
c These totals are for mine output and aggregate more than if smelters' and refiners' figures were used.

Metals produced in Bingham (West Mountain) district, 1865–1917, by periods.

Period.	Ore, short tons.	Gold.		Silver.		Copper.		Lead.		Recoverable zinc.		Total value.
		Fine ounces.	Value.	Fine ounces.	Value.	Pounds.	Value.	Pounds.	Value.	Pounds.	Value.	
1865–1880.	....	69, 028.00	$1, 426, 926	4, 940, 097	$5, 961, 278	2, 058, 900	$416, 401	124, 430, 704	$6, 745, 707	....	....	$14, 550, 312
1881–1890.	....	42, 518.00	878, 924	6, 364, 168	6, 660, 742	2, 155, 780	315, 140	157, 485, 700	6, 813, 566	....	....	14, 668, 372
1891–1900.	....	85, 245.00	1, 762, 171	5, 256, 464	3, 831, 732	16, 726, 571	2, 492, 268	140, 501, 994	5, 229, 104	....	....	13, 315, 275
1901–1910.	....	581, 351.04	12, 017, 572	13, 661, 758	8, 010, 313	478, 607, 954	69, 101, 973	158, 296, 838	7, 450, 422	4, 221, 889	227, 982	96, 808, 262
1911–1917.	66, 225, 137	736, 876.86	15, 232, 597	18, 193, 337	11, 201, 055	1,159,087,661	224, 282, 414	477, 377, 302	26, 190, 654	35, 830, 829	3, 450, 745	280, 357, 465
	....	1, 515, 018.90	31, 318, 190	48, 415, 824	35, 665, 120	1,658,636,866	296, 608, 196	1,058,092,538	52, 429, 453	40, 052, 718	3, 678, 727	419, 699, 686

Platinum, palladium, bismuth, and other rare metals have been collected in the blister copper. Eilers[1] gives their content in the blister copper from the Garfield smelter, which derives most of its ore and concentrates from the Bingham district, as follows:

Content of precious and rare metals per 100 tons of blister copper from Garfield smelter.

	Ounces.
Gold	288
Silver	3,480
Platinum	.432
Palladium	1.183
	Pounds.
Selenium	56.0
Tellurium	5.54
Bismuth	6.1
Nickel	40.0

ORE RESERVES.

No close estimate of the total ore reserves of the district can be made. It is not the policy of the companies to block out large reserves of ore in limestone in advance of requirements, and the actual ore in sight by no means indicates the possibilities or probabilities in this class of ore.

It has not yet been demonstrated to what depth mining can be profitably carried on in this class of deposits, but it has been shown that the ores generally decrease in value with increase in depth, and in some of the deeper mines the indications are that the profitable limit under present conditions is not far distant. The size as well as the grade of the ore bodies also rather generally decreases with depth, and the probability of finding rich ore bodies at great depth is probably not great. However, considerable areas of promising ground have not yet been thoroughly prospected, and there are good reasons for expecting that important bodies of ore may be found in them. The extent of the limestones in the neighborhood of Carr Fork, including the Highland Boy, Yampa, and smaller beds or lentils, is relatively small, and the possibilities are less than in the much more extensive Jordan and Commercial limestones. Recent developments have revealed small beds of limestone, not known from surface exposures, some of which contain important ore bodies, and it is entirely possible that other beds will be found in future development. The largest and richest bodies of ores of the replacement vein type have probably been discovered, but there is little doubt that this type of deposit will continue to furnish a large amount of ore for years to come.

The nature of the disseminated ores favors prospecting by churn drills and permits the development of large bodies at relatively low cost, and the extent of the operations makes this desirable and necessary. Very large bodies of this type of ore have therefore been demonstrated, and will doubtless be supplemented from territory not yet prospected. Further, the depth to which the deposits extend in workable amounts has not yet been fully demonstrated. The Utah Copper Co. at the close of 1916 reported that there had been 424,524,000 tons of ore developed and partly developed, with an average copper content of 1.415 per cent, of which 369,845,000 remained to be mined. On March 15, 1909, the Ohio Copper Co. reported 13,484,865 tons of positive and probable ore with an average copper content of 1.606 per cent. It is evident that without further prospecting the district has sufficient ore of this type to supply the present milling capacity for years to come.

PHYSIOGRAPHY.

Topographically the district has rather strong relief, the elevations ranging from about 5,500 feet in the valley near the mouth of Bingham Canyon to about 9,200 feet at the summit of Clipper Peak. In general, the area presents the characteristics of a region in a mature stage of erosional development—that is, it has been dissected into a series of ridges and spurs with rather uniform slopes. A few areas of more resistant rocks have formed cliffs or steep slopes, and most of the minor irregularities, due to differences in the resistance of the different rock, are masked by the abundant float from the breaking down of the much-jointed quartzite that forms a large part of the rock of the district.

The slopes of the main valleys for several hundred feet above the present stream beds are much steeper than the general slopes, so that this portion of the valleys has the character of canyons and exhibits a young stage in stream development. At many points terrace deposits of stream gravels mark the line where this change of slope takes place.

At present the streams are cutting in gravels that have partly filled the lower parts of the

[1] Eilers, A., Am. Inst. Min. Eng. Bull. 78, p. 999, 1913.

canyons. Boutwell and Keith have shown that the "terrace gravels" slope more steeply to the east than do the present streams and have attributed the cutting in the lower portion of the valleys to differential uplift that tilted the range to the east. From observations over a wide area in western Utah the writer is led to believe that the cause for this renewal of down cutting was widespread rather than local and is inclined to attribute it to a general change, perhaps climatic, rather than to local changes in elevation. Certain features, however, seem to be most readily explained by differential movement, and it is recognized that this may have played a part.

GEOLOGY.

The rocks of the district include consolidated sedimentary rocks, unconsolidated sediments, intrusive rocks, and extrusive rocks. (See Pl. XXXIII, in pocket.)

SEDIMENTARY ROCKS.

The sedimentary rocks of the district are the Bingham quartzite, predominantly quartzite, with subordinate members or lentils of limestone and shaly and limy sandstones.

BINGHAM QUARTZITE.

The Bingham quartzite, which is by far the most widespread rock of the district, is a rather fine grained, usually nearly white quartzite, which shows a remarkable uniformity of character throughout its great thickness. It contains a few beds of pebbly conglomerate and locally it becomes shaly or limy, but for the most part it is composed of quartz grains cemented with silica and is everywhere almost identical in appearance. Except in the vicinity of limestone the bedding is usually obscure, owing in part to the massive character of the quartzite and in part to the presence of joints which have broken the quartzite into small blocks rarely more than a few inches in dimension. These abundant joints tend to obscure the indistinct bedding planes where the quartzite outcrops and cause it to break down readily, so that its surface is very largely mantled with a variable thickness of these angular fragments.

The thickness of the Bingham quartzite is somewhat uncertain, owing to the difficulty of recognizing duplications by faulting in a formation of such uniform character. Keith has estimated the thickness in the Bingham district at 8,000 to 10,000 feet. Its age as determined by fossils in the limestones interbedded with the quartzite is upper Carboniferous (Pennsylvanian), and it has been correlated with the Weber quartzite of the Wasatch range.

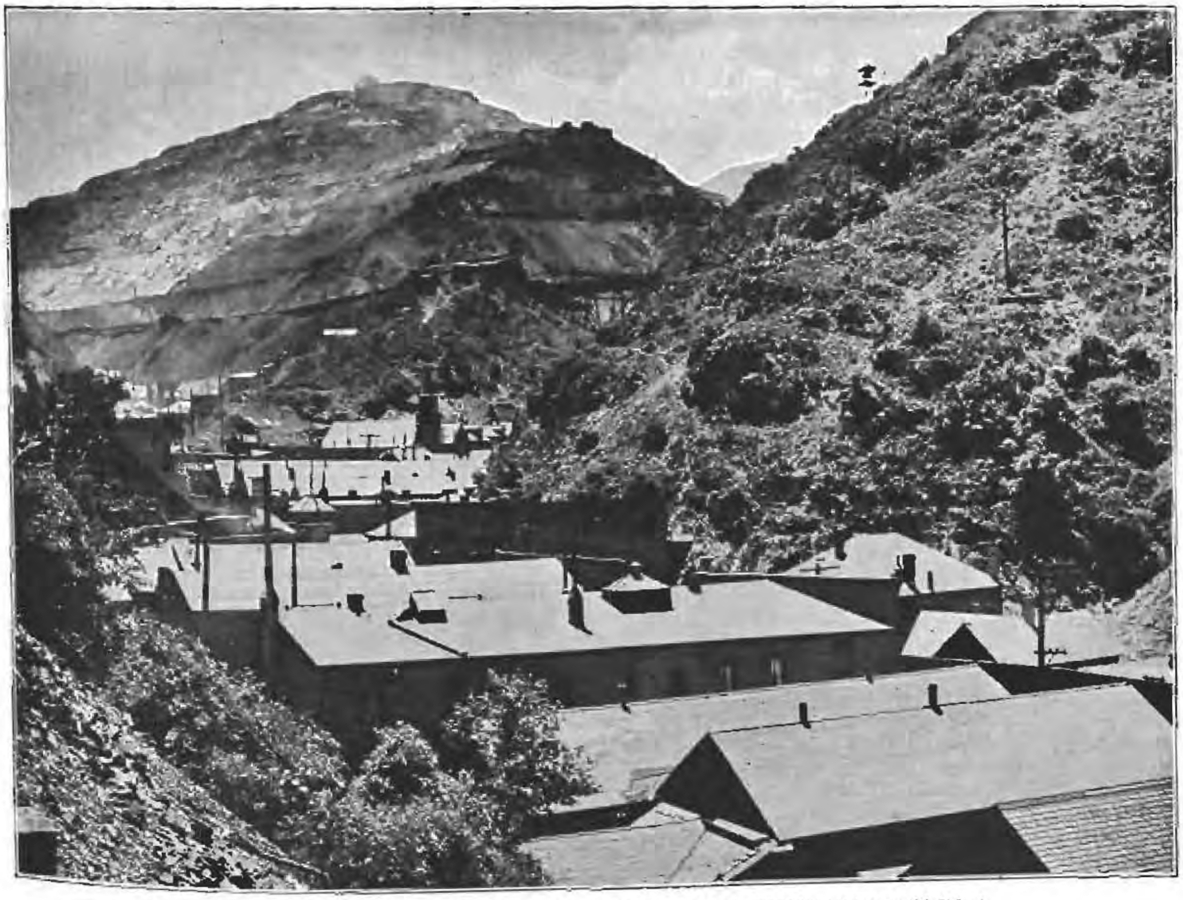
LIMESTONES INTERBEDDED IN BINGHAM QUARTZITE.

The limestones, though of minor importance from a stratigraphic standpoint, are of great economic importance on account of their relations to the ore deposits. The limestone bodies are characteristically lenticular in form, thinning and thickening along both the strike and dip and even completely pinching out, so that it is frequently impossible to follow a given bed for long distances on the surface. This difficulty is increased by the abundance of float. There are many of these lenses in the quartzite. Keith says: "Almost any section where the rocks are continuously exposed for a hundred yards will show one or more layers of limestone or calcareous sandstone." Most of the contacts of limestone and quartzite are sharp, but some of them are gradual, the rocks merging through sandy layers or alternating layers of limestone and sandstone. Along the strike the beds either gradually pinch out or pass into sandy layers and finally into normal quartzite.

Though calcareous layers are not infrequent through the formation the important Jordan and Commercial limestones occur in the lower part, and the Highland Boy, Yampa, and other limestones possibly considerably higher. It has been suggested, though not positively demonstrated, that the apparently higher beds are the same as the lower and have been forced to their present position by the intrusion of the Last Chance monzonite mass. It seems not improbable that the Highland Boy and the overlying limestones are lenses deposited at a considerably higher horizon than the Jordan and Commercial beds.

The unaltered limestones are usually composed of gray, blue, or even nearly black strata. These different colored beds are lenticular in places at least, as is especially well shown in the Yampa limestone. In following this limestone down the dip in mining operations the gray limestone has in part given place on the hanging wall to black limestone. As greater dip is

A. VIEW OF BINGHAM CANYON IN 1900, SHOWING LOCATION OF DISSEMINATED DEPOSITS.



B. VIEW OF BINGHAM CANYON IN 1914 FROM SAME POINT AS SHOWN IN *A.*

gained the black limestone thickens and the gray limestone correspondingly thins till in places it has been almost wholly displaced.

Many of the limestone beds are siliceous, the silica being present either as sand grains or as chert. In some beds the chert appears as small nodular masses; in other beds it forms the greater part.

In the vicinity of some of the intrusive masses and in some places where the intrusives are not known to be in close proximity the limestones have been recrystallized to white marble and contain lime-iron silicates in small amounts. The "contact silicates," however, are much less abundant in this district than in several others.

The following tables [1] show the composition of some of the limestones and the chemical changes resulting from their alteration:

Analyses showing changes undergone by limestone during metamorphism.

[Analyst, W. F. Hillebrand.]

	1		2	
	Gray.	White.	Gray.	White.
SiO_2	4.87	43.40	12.50	50.41
Al_2O_3, Fe_2O_3	.30	....	1.99	[a] .80
MgO	.99	1.31	3.66	24.57
CaO	53.50	45.62	48.34	9.74
H_2O-, H_2O+	....	.23	4.31	11.81
CO_2	39.32	8.28	28.06	1.61
P_2O_5	....	....	.56	.15
SO_3	....	....	([b])	....
MnO	....	....	....	Trace.

	3	4	5
SiO_2	27.78	27.76	34.36
MgO	.34	6.09	6.09
CaO	39.98	38.91	35.99
CO_2	30.76	24.28	25.91

[a] Approximately. [b] Undetermined.

1. No. 7 tunnel, Highland Boy mine.
2. Emma West drift, Old Jordan mine.
3. Blue limestone from south slope of West Mountain, on road to Tooele.
4. Slightly marmarized limestone from same locality.
5. Marble from same locality.

The last three analyses in the table are of specimens from the same bed showing changes that take place during alteration, No. 3 being least altered and No. 5 most altered. The first two analyses are of material taken from opposite ends of a single specimen, the "gray" being the least altered. In all the analyses the notable change is the increase in silica and magnesia and the decrease in calcium and carbon dioxide.

Although the Bingham quartzite contains many limestone and calcareous beds, the important ones are relatively few. Keith and Boutwell have mapped and described eight limestone members and lentils—the Butterfield limestone, maximum thickness in the district about 300 feet; the Lenox limestone, maximum thickness 200 feet; the Jordan limestone and the Commercial limestone, each with an average thickness of about 200 feet; the Highland Boy limestone, maximum thickness about 400 feet; the Yampa limestone, maximum thickness about 400 feet, though in most places much less; the Tilden limestone, maximum thickness about 300 feet; and the Phoenix limestone, maximum thickness 300 feet. Numerous other limestone lentils, some of which are economically important, are present. Most of the members vary markedly in thickness along both the strike and the dip.

RECENT DEPOSITS.

The recent unconsolidated deposits consist of terrace gravels and present stream deposits. The terrace gravels are present about the base of the range and extend into the canyons as terraces on the canyon walls above the present stream. The latest deposits are those that are still being laid down by the streams. Both the early and the present stream deposits have been worked for placer gold.

INTRUSIVE ROCKS.

DISTRIBUTION AND CHARACTER.

The intrusive rocks of the Bingham district are intimately associated with the ore deposits and are therefore of especial importance. They are of considerable areal extent and occur as irregular stocklike bodies, as dikes and sills, and possibly as laccolithic bodies. The two largest bodies in the district are the Bingham stock, which is near the head of Bingham Canyon and which contains the main body of the disseminated ore (see Pl. XXXIV), and the Last Chance stock, which is at the head of Carr Fork and which contains

[1] U. S. Geol. Survey Prof. Paper 38, pp. 189, 191, 1905.

the Last Chance and other lead-silver deposits. There seems to be no good reason for considering either of these bodies as a true laccolith. The Bingham stock has been exposed by erosion to a depth of about 1,500 feet and has been drilled to a greater depth without showing any evidence that it does not extend indefinitely without marked decrease in size. The same is possibly true of the Last Chance body. Within an area of several square miles east of these main bodies are numerous smaller bodies of intrusive rock, some of which may be laccolithic in character. North, northwest, south, and southeast of the main bodies sills, intruded along the stratification planes of the sedimentary rocks, can be traced more or less continuously for long distances. In the vicinity of the main intrusive masses numerous dikes cut the sedimentary rocks.

COMPOSITION.

The intrusive rock in different localities differs considerably both in texture and in mineral and chemical composition. Moreover, in certain areas, especially in the Bingham body, it has been so altered that its original character is largely obscured. The rock is of medium composition and may be classed as monzonite, though in many places it contains sufficient quartz to warrant calling it quartz monzonite, and in others it is distinctly dioritic. In many places the gradation from one type to another can be directly traced, and there can be little doubt that all the intrusives were derived from a common magma.

The general composition of the intrusives of the district has been described by Keith [1] as follows:

Two general lithologic varieties of "monzonite" are seen. The principal one is typified by the great masses between Carr Fork and Bingham Canyon and consists of a massive holocrystalline rock of medium grain and dark color. The other appears in many of the smaller dikes and sills, as at the Fortune and Zelnora mines, and consists of a coarsely porphyritic rock of gray color. The latter are directly connected with the former at the surface and in the same rock mass. Between these two extremes there are sundry facies of texture.

The monzonite is usually a dark gray, brown, or black rock, whose surfaces weather gray or rusty brown. The gray aspect is due to the feldspar, especially in the porphyritic varieties, and increases with the amount of that mineral, while the darker colors are caused by the biotite, hornblende, and augite. A rusty and brown appearance is often caused by the oxidation of the iron-bearing minerals, while decomposition of the feldspars in other places gives a whitish surface to the rock. The monzonite is composed principally of feldspar, with biotite, hornblende, augite, and quartz. All of these may appear in one rock, or the feldspars may occur with any combination of the others. As a rule, the orthoclase feldspars are numerous; in places, however, plagioclase feldspar prevails and the rock has a dioritic facies. Quartz is rarely seen in the hand specimen, but appears frequently in the thin section. It varies considerably in amount, and in places its quantity is sufficient to give the rock a decided resemblance to granite. In the porphyritic varieties small, corroded phenocrysts of quartz are sometimes to be seen. Usually, however, quartz is not a prominent constituent of the rock. Besides the principal constituents, feldspar, biotite, hornblende, and augite, and the minerals of the metalliferous deposits, there are few coarse minerals to be seen in the monzonite. Magnetite, pyrite, and chalcopyrite are found in small grains and are widely distributed through the rock. One or more of them is found in every thin section. Epidote appears here and there, but very sparingly. A little secondary calcite, chlorite, and muscovite are also found. The composition of the rock is simple, and practically all of the minerals are visible to the eye in one place or another.

In the monzonite porphyry two generations of minerals are found—(1) the porphyritic, in crystals from one-eighth to one-half inch long, and (2) the groundmass, of granular nature, in which the crystals range from one-eighth of an inch down to microscopic size. Feldspar and biotite are the minerals which usually compose the phenocrysts. Pyroxene is much less common than the other minerals either in the phenocrysts or in the groundmass. One section shows phenocrysts of quartz, which are very uncommon. Phenocrysts of orthoclase are conspicuous in the porphyry north of the Fortune mine. In the groundmass, however, both orthoclase and plagioclase feldspars are usually present. Porphyritic biotite characterizes the bodies of the formation south of Telegraph and Niagara mines. This variety of the monzonite porphyry is also marked by a very fine grain, most of the minerals being of microscopic size. This rock when fresh is of light-gray color, and underground it is very difficult to distinguish it from the quartzite and the cherty marble. On the surface, also, the same difficulty is encountered, for the porphyry weathers in fine, structureless fragments that are remarkably like the limestone and quartzite. It very closely resembles the weathered siliceous marble and quartzite, and only by the more or less bleached crystals of biotite can the porphyry be distinguished from the other rocks.

The fine-grained monzonite is not confined to the two localities above mentioned but is often to be seen near the contact of the monzonite with the other formations, in the smaller intrusive bodies, and even in the large masses. The smaller portions are not always characterized by this fine grain, however, but frequently are composed of monzonite porphyry of coarser grain than that seen in some of the largest masses. The great body of monzonite surrounding the Last Chance mine, for instance, contains no rock so coarse as that which is found in the nar-

[1] Keith, Arthur, Descriptive geology of the Bingham mining district, Utah: U. S. Geol. Survey Prof. Paper 38, p. 51, 1905.

row sill that passes through the Fortune mine or as that which appears in one or two of the narrow dikes at the head of Carr Fork and Tooele Canyon. In a general way, however, it seems clear that the formation is coarser in the eastern bodies.

METAMORPHISM.

Character.—That the rock of the Bingham stock has been highly altered has not been universally recognized. Some men, who are thoroughly familiar with the rock, which constitutes the disseminated ore, maintain that it shows no important alteration except that due to surface waters or to weathering and that the primary ore and gangue minerals are original crystallizations from the magma. This belief has also found expression in the literature of the district,[1] although it was advanced before the extent of the disseminated ores had been fully recognized.

This hypothesis is by no means without foundation and may appear very natural on superficial examination. Microscopic and chemical study and field evidence seem to the writer, however, fully to justify Boutwell's conclusion[2] that the rock has suffered extensive hydrothermal alteration, and that to this the primary mineralization is due.

The entire Bingham stock seems to have been affected by the alteration, and it is therefore impossible positively to determine its original character. Study of the less altered portions and of the field relations indicates that the original rock did not differ materially from that of the Last Chance and other bodies in the area. The main differences are probably due to secondary alteration.

The freshest rock of the Last Chance body is composed of orthoclase, plagioclase, augite, and biotite, rather abundant magnetite, or some magnetic iron mineral, small amounts of apatite and rutile, and a few crystals of zircon. The plagioclase feldspars vary in composition, but are all acidic, none being observed more basic than andesine. Many crystals of twinned plagioclase are surrounded by a graphic intergrowth of two untwinned feldspars with different indexes, both lower than that of the central crystal. Such intergrowths are also present without the central core of plagioclase. Other crystals of untwinned feldspar are composed entirely of orthoclase. Many augite crystals have been partly altered to a light-green, slightly pleochroic amphibole and, where alteration has progressed slightly farther, partly to chlorite.

The orthoclase is slightly clouded with an undetermined mineral, which possibly marks the beginning of sericitization. Where alteration is more intense the plagioclase contains a little epidote and in some specimens a little biotite. Biotite usually shows little alteration, but in some specimens a little epidote has developed along cleavages and in many others a little carbonate.

In the Bingham stock two distinct types of rock or ore are probably due to differences in the intensity rather than in the character of the alteration. These are recognized in the ore as the dark "porphyry" and the light "porphyry" and may well be described under these heads, though every gradation between these types may be found.

Dark "porphyry."—The typical dark "porphyry" is a dark brownish gray mottled rock. The dark minerals are grouped in irregular areas that give much of the rock a porphyritic appearance. Biotite, feldspar, and sulphides are the only minerals that can be readily recognized in the hand specimen. In the extreme type this rock has a rather uniform dark-brown color, which is due to the abundance of biotite and especially to its presence on fractures along which the rock breaks. The microscope shows that the biotite is the only original mineral that has not undergone marked alteration and that in some specimens even the biotite has been altered. The pyroxene and hornblende of the original rock have with few exceptions been entirely altered, the areas occupied by these minerals being occupied by irregular masses of small biotite foils. (See Pl. XVI, *A*, p. 165.) Some of the phenocrysts of original biotite have been attacked and the biotite redeposited as small foils. The plagioclase crystals are represented by areas of sericite and quartz and in some specimens by biotite. The orthoclase crystals show relatively slight alteration, but nearly all of them contain some sericite and some of them biotite, and in more advanced stages of alteration they are partly replaced by secondary orthoclase in small crystals. Magnetite, which is rather abundant in the fresh rock, is absent in

[1] Keith, Arthur, op. cit., p. 64.
[2] Boutwell, J. M., Economic geology of the Bingham mining district, Utah: U. S. Geol. Survey Prof. Paper 38, p. 172, 1905.

extensively altered rock. In much of the altered rock small irregular crystals of rutile are rather abundant. The secondary biotite, which is the characteristic mineral of the dark "porphyry," differs from the original biotite in being in small foils and in being distinctly lighter in color, ranging from an olive-green with pleochroism in varying intensity to light brown with pleochroism much less pronounced than that of the original mica.

Where alteration has been relatively intense the original biotite phenocrysts have been entirely altered, and the secondary mica, instead of occupying approximately the area of the mineral from which it was formed, is disseminated rather uniformly through the mass. Granular quartz and clear unaltered orthoclase, evidently both secondary, occur in places. Sulphides are disseminated irregularly through the rock.

Light "porphyry."—The light "porphyry" is a light-gray rock in which phenocrysts of feldspar and grains of sulphide can be recognized in the hand specimen. Under the microscope it is seen to be composed of phenocrysts of feldspar and some crystals of altered biotite in a fine granular groundmass. (See Pl. XVI, *B*, p. 165.) The original phenocrysts of feldspar are orthoclase, and all of them contain numerous foils of sericite, which in many is very abundant. Other areas are composed of a felted mass of sericite that may represent altered plagioclase crystals. The few mica phenocrysts are largely bleached to a colorless mica but contain small lenses of brown mica showing their derivation from biotite. The groundmass which forms a large percentage of the rock is composed of a fine granular intergrowth of clear orthoclase and quartz with some foils of sericite. In many specimens this granular groundmass embays the orthoclase crystals and extends along fractures and cleavages; there can be no doubt that the orthoclase phenocrysts are being altered to material of the character of the groundmass, and it is but natural to conclude that the feldspar of the groundmass represents in part an alteration of the earlier feldspar of the rock.

The rock is cut by small veinlets composed of quartz or quartz and orthoclase and grains of sulphide. The larger veinlets, which are very abundant in many places, are composed of quartz, so far as observed, but many of the small veinlets contain much orthoclase. There is no known difference in the age or occurrence of these veins, and there is doubtless every gradation from one to the other.

The original sulphides—pyrite and chalcopyrite with some bornite—are disseminated through the rock and are present in the veins where they have usually been the latest minerals to form, filling the spaces between quartz crystals.

Molybdenite in small flakes is disseminated through the rock in many places, and in a few it is rather abundant in veinlets, where it crystallized in part earlier than the quartz.

A light-colored type of "porphyry" containing numerous crystals of a yellow micaceous mineral is seen under the microscope to be highly sericitized. The yellow crystals are biotite that has been bleached to a nearly colorless mica, probably muscovite filled with yellow grains of rutile. Though some of the fresh mica contains inclusions of rutile, none of them were observed to contain them so abundantly as the altered grains, and it is probable that the rutile has resulted in part at least from the alteration of the mica or of included ilmenite. These micaceous flakes were noted especially in the so-called "Pay Roll" porphyry and are said to be rather typical of this part of the altered area. They are less abundant, however, in specimens from other locations.

The typical changes that have taken place in the mineral composition of the monzonite during alteration are the almost or complete alteration of augite, hornblende, plagioclase, and magnetite, and the partial alteration of the orthoclase and biotite to sericite, secondary biotite, quartz, and secondary orthoclase. In the dark porphyry the secondary biotite is abundant and the secondary orthoclase has been little developed. In the light porphyry biotite is of slight importance and secondary orthoclase and quartz make up a large part of the rock.

Alteration near lead-silver veins.—The alteration of the rock adjacent to the lead-silver fissures is in a general way similar to that of the Bingham stock, though it extends but a short distance from the fissure. In the incipient stages of alteration epidote and calcite are relatively abundant and the more intensely altered rock immediately adjacent to the

fissures is composed of felted areas of sericite, probably representing feldspar phenocrysts, partly sericitized untwinned feldspar of the original groundmass and a secondary groundmass composed of a granular intergrowth of orthoclase and quartz.

Much of the sericitic mineral is light brown and has a rather faint pleochroism, indicating that it is not pure muscovite. Rutile is rather abundant. The rock is cut by small veinlets composed of quartz and orthoclase, many of which seem to merge into the secondary groundmass. In the veinlets the orthoclase completed its crystallization later than the quartz and is commonly interstitial. The opposite, however, is true in much of the groundmass, the quartz crystals including well-formed crystals of orthoclase. The older generation of feldspars are being attacked and worked over into a granular mass similar to that of the groundmass. This rock in advanced stages of alteration is similar in silicate mineral composition to the light "porphyry" copper ore.

The chemical and mineralogic changes due to alteration are further discussed on page 164.

EXTRUSIVE ROCKS.

The extrusive rocks of the Bingham district occur only along the desert valley bordering the Oquirrh Range and are not known to be of economic importance. Keith[1] has described the formation as follows:

> Most of the formation consists of massive or porphyritic andesites. Large masses of the breccia are seen, however, in the exposures near the Oquirrh Mountains. The rock of the andesite group seems to have been deposited as an overflow upon an existing surface. Its contact with the Carboniferous rocks is almost invariably covered with loose quartzite wash, so that its exact nature has not been determined. At certain points, for instance, near Dalton and Lark mine, it appears to cut across the edges of the quartzite like a dike. Half a mile farther north a similar but less definite arrangement is seen. Usually, however, the andesitic rocks occupy low ground around and between the quartzites, as if deposited in previously formed hollows. Possibly the mass at the Dalton and Lark mine occupies one of the vents through which came the bulk of the formation. It is equally possible that the visible arrangement is due to subsequent faulting.
>
> The andesites are usually fine or medium grained rocks of dark color. Exposure and disintegration produce a light or dark gray color through the alteration of the feldspars. In most places the rock has a porphyritic habit. While this is seldom conspicuous, occasionally the phenocrysts are coarse and large, as, for instance, one-half mile northeast and east of Fortune mine.
>
> The principal minerals of the andesite are plagioclase feldspar, green hornblende, augite, and biotite. Besides these there are small amounts of quartz, orthoclase, magnetite, pyrite, and chlorite. Of these minerals the plagioclase, hornblende, and augite appear as phenocrysts. The feldspar usually forms stubby crystals. In one instance the crystals are slim, with a somewhat ophitic structure. The hornblende and augite form irregular and patchy crystals. The same minerals appear in the groundmass in very fine grains and crystals. Chemical examination indicates an approach to latite in composition.
>
> Portions of the formation consist of andesite fragments, less than a foot in diameter, embedded in a matrix of andesite. The fragments are of about the same composition as the matrix and probably result from the partial solidification and breaking up of the lava as it flowed. In this respect they differ little from some of the monzonite contact breccias, but are quite unlike other breccias shown in the mountains, where the monzonite was crushed by faulting movements that took place long after its intrusion.
>
> In the vicinity of Lead mine one of these breccias rests upon a surface of decayed andesite and soil. From this it is evident that one brecciated flow followed an interval of exposure to erosion. The lapse of time shown thereby was probably not great. * * * Apparently they conform nearly to the present surface and have not been greatly eroded since their formation. Thus is furnished a probability of their recent origin.

RELATIONS AND AGE OF THE IGNEOUS ROCKS.

The intrusive and extrusive rocks have nowhere been found in contact in a manner that furnishes conclusive evidence as to their relative ages. The extrusive rocks lie against the range in a manner which suggests that they flowed against it after it had been eroded to approximately its present form. If this be true they are distinctly later than the intrusive rocks. In the Tintic district in the southern extension of the Oquirrh Range it has been shown that intrusive and extrusive rocks of essentially the same character as those at Bingham are contemporaneous in age and the same may hold true at Bingham. The writer knows of no positive evidence to show that the intrusive are older than the extrusive rocks.

Owing to the absence of sedimentary rocks later than the Carboniferous (except the recent sediments) it is not possible to determine directly the age of the igneous rocks except that they are post-Carboniferous. The marked similarity of the lavas to those in other sections of the State, however, leads to the belief that they are of essentially the same age. If this

[1] Keith, Arthur, op. cit., p. 55.

correlation is correct they are of Tertiary age. (See p. 99.)

STRUCTURE.

Both folds and faults are important structural features of the Bingham district. Joints and fissures are economically important, and joints are important in determining the rapidity with which the formations were eroded.

FOLDS.

The folding in the district has been described by Keith [1] as follows:

> The folds exhibited are of two kinds, broad open flexures whose dips persist for miles, and small rolls, whose dimensions are measured by a few hundred feet. Of the former class only one appears within the Bingham district—a synclinal fold whose axis passes in a northwest direction just below the mouth of Carr Fork. On the southwest side of the axis the rocks dip toward the north and on the northeast side they dip toward the west. Thus, they constitute a fold which pitches toward the northwest and brings to the surface successively younger beds in that direction. On account of this pitch the oldest Carboniferous strata of the district, which appear in Butterfield Canyon, are not exhibited in any other part of the district but are overlain elsewhere by the younger quartzites and limestones in the order of their deposition. Thus, the youngest rocks shown within the area of the map are those appearing north and northeast of Markham Peak. The syncline which passes near Carr Fork might well be called the Bingham syncline. The anticline corresponding to it is seen in the upper part of Butterfield Canyon. * * * This has the same northwestward pitch, so that the formations on its west side dip approximately westward and parallel the line of the Oquirrh Mountains from Butterfield Canyon southward. Similar large folds characterize the Oquirrh Mountains throughout their extent, and their axes have approximately the same northwestern trend and pitch. These folds were produced during the first known deformation of the region, by compression in a northeast-southwest direction. By them the uplift of the region was initiated and to them is due the greater part of the actual uplift.
>
> The folds of the second order, which are recognized in the different mines under the term "rolls," are not so clearly of this origin. They seldom affect the outcrop of the formations but have been observed in several mines in working out the ore bodies and the contacts of limestone and quartzite. They are local warpings in a general plane of dip rather than well-defined folds with dips in opposite directions. The dips, which are reversed or contrary to the prevailing dip in the locality, are usually very slight and hardly more than flat. In the Niagara mine a roll has been worked out along an ore body. The average dip in the locality is 30° N., but for a width of a few feet north and south of the roll this is replaced by a slight, nearly flat dip to the south.
>
> These minor folds appear to be somewhat complicated by faults and are associated with them. It is possible that they are in part due to dislocation along fault planes. As the different blocks of the earth's crust moved past one another they were undoubtedly more or less dragged, one upon the other. Unless the faults were absolutely parallel in plane, when motion took place there would be a certain amount of wedging together and compression of some of the fault blocks. This might readily have caused local folds of this order. That such is the case, however, can not be definitely stated.

A minor fold or "roll" in the workings of the Old Jordan mine is ascribed by Boutwell [2] to strike faulting. In places "rolls" are undoubtedly accompanied by strike faulting, but in other places they seem to be simply a local "buckling" of the beds, which in one direction may pass into strike faulting and in the others into the normal dip of the beds. Many of these minor folds are of prime economic importance.

FAULTS AND FISSURES.

Surficial evidences.—Fissures and faults are abundant in all parts of the Bingham district. Many of the fissures show no mineralization and are therefore not conspicuous, and many of those along which there has been movement are hardly more evident, owing to the uniformity of formations over considerable areas. These facts, together with the abundance of float in the district, make it exceedingly difficult, and in many places impossible, to locate and trace on the surface even the stronger fissures. In the underground workings, however, they are apparent.

Character.—The character of the fractures in the Bingham district differs considerably. Boutwell [3] says:

> The fractures of Bingham vary widely in general character. They range from a network of irregular cracks and zones of intense crushing to simple individual fissures and zones of fissures. The type which most commonly bears ore is a simple fissure characterized by a zone of finely comminuted gouge, averaging 1 to 4 feet in width and inclosed between slickensided walls. When such fissures carry ore, as along portions of the Galena, Silver Shield, Winamuck, Last Chance, and Montezuma fissures, they constitute normal veins. Groups or zones of fissures of this type are occasionally encountered. When they are ore-bearing, as in an instance on the Last Chance mine, British tunnel level, they constitute lodes. This characteristic lode consists of a zone of crushed, altered, slightly mineralized monzonite, 8 to 10 feet wide, lying between slickensided walls of the same rock and traversed by two strong veins and a number of minor seams. There are many gradations from these two most important types. One of these which directly influenced the forma-

[1] Keith, Arthur, op. cit., p. 56.

[2] Boutwell, J. M., op. cit., p. 140.

[3] Idem, p. 136.

tion of some of the principal ore bodies in Bingham consists of an indefinite series of parallel fracture planes or fissures, each of which, unlike those which grouped in a crushed zone form a lode, preserve its individual character, and cuts the country in a direction roughly parallel to the strike and dip at an angle steeper than that of the bedding. A typical example of this class of fissures is in the Highland Boy mine.

Another type of fracturing is exhibited by a complex network of fracture planes, which occurs throughout the monzonite mass in Copper Center Gulch. So completely has this rock been thus broken up that one is practically unable to obtain a hand specimen a few inches in width which does not show these planes. This character of regional crushing is seen in quartzite along the roadside in Markham Gulch below the Ben Butler and in black shale in the Red Wing mine. Again, single fissures formed by movement along contacts or between sedimentary beds are common and frequently carry ore. In the Fortune ore was deposited along a plane of movement between a massive quartzite and an overlying porphyry sill. In the Montezuma the ore bodies formed for a portion of their extent along a plane of movement between two beds of black shale.

Distribution.—The general distribution of the fissures is given by Boutwell [1] as follows:

Fissuring took place in all parts of this district and appears to have reached a maximum in the region about the head of Bingham Canyon, Muddy Fork, and upper Carr Fork. The intense fissuring and faulting which characterize this region extend north through ground opened by the Last Chance, Nast, Boston Consolidated, Highland Boy, York, and Petro mines; south through Ashland, Albion, and Neptune ground; and east through Old Jordan, Commercial, Niagara, and Telegraph ground. The crushing, fracturing, and fissuring which have occurred in this general region are beyond detailed description. Only a comparatively small portion of the several hundred fissures observed underground are recognizable at the surface. * * *

Strong fissures are not limited in their occurrence, however, to this particular area. Among the large number which have been found north of this locality are the Midland, Winamuck, and Dixon fissures in Main Bingham Gulch; the Julia Dean, Amazon, Liberal, Montezuma, Hoogley, and Rosa fissures in Markham Gulch; the U-and-I fissure in Dixon Gulch, and the Phoenix, Caromandel, and Cuba in lower Carr Fork. Types of strong fissures to the south of the central locality may be seen in the St. James, Eagle Bird, and Queen fissures. In brief, strong fissuring has taken place throughout the Bingham district.

Trend and dip.—* * * In general it appears that the fissures noted in which no metallic contents were observed trend toward all points of the compass in about equal numbers. If any distinct group of fissures is indicated by these trends it would appear that the greater number trend north-northwest, north, or north-northeast—that is, between N. 25° E. and N. 20° W. The observed fissures which inclose some metal, but insufficient to pay for mining, trend with a few known exceptions northeast-southwest. And far the greater portion of these lie between N. 5° and 43° E. Finally, over 84 per cent of the observed fissures known to carry *pay* ore trend northeast-southwest, ranging between N. 5° and 43° E. Among them are included the Montezuma, Erie, Dixon, St. James, Colorado, Neptune, Spiritualist, Last Chance, Silver Shield, U-and-I, Tiewaukee, Ferguson, and Nast lodes. Those mentioned from the Colorado to the Nast, inclusive, trend between N. 39° and 46° E. Among the very small number of exceptions to the prevailing northeast trend of pay lodes are the Phoenix, Daylight-Extension, Winamuck, Hoogley, and Midland. In brief, of the cases observed, the barren fissures display no distinct trend, the poorly mineralized fissures and the pay lodes with very few exceptions trend northeast-southwest.

The measurements of dips indicate that of those observed far the greater portion of the barren fissures dip toward the northwest, that a little more than 80 per cent of the poorly mineralized fissures dip toward the northwest, and that over 85 per cent of the pay lodes dip toward the northwest. Very few gently dipping slips or fissures were found. Over 90 per cent of the pay lodes observed dip between 45° and 90°. In brief, the prevailing dip of both barren and mineralized fissures observed is toward the northwest, and the prevailing degrees of dip noted are from 45° to 90°.

Age.—The relative dates of fissuring are discussed by Boutwell [2] as follows:

* * * Although the evidence is not complete nor without apparent slight contradictions, it clearly indicates that fissuring occurred at distinct periods before and after the deposition of ore. * * *

The facts indicate that the principal fissuring occurred after intrusion; that extensive fissuring in northeast-southwest (and north-south) directions preceded the deposition of the principal lead and silver ores; that some fissuring probably occurred on east-west (northwest-southeast) planes before the deposition of the copper ores; that faulting along northwest-southeast and east-west planes followed the deposition of the main copper ores, and that pronounced movement on northeast-southwest (and north-south) planes followed both the northwest-southeast faulting and the deposition of lead and silver and copper ores. In brief, fissuring occurred successively in northeast-southwest (east-west), northwest-southeast, and northeast-southwest directions in at least three distinct periods.

Most of the fissuring evidently occurred after the intrusion of the monzonite, and the mineral-bearing fissures were probably formed very shortly after the instrusion. How much later the subsequent fissures were formed is uncertain.

Displacement.—The displacements have been discussed by Boutwell,[3] as follows:

* * * They include faults trending with the strike of the sediments and trending with and oblique to the dip; faults trending transverse to the strike and dipping in either direction; faults whose probable inclination departs

[1] Idem, p. 136.

[2] Idem, p. 138.

[3] Idem, p. 140.

only slightly from the horizontal; faults trending with the strike and others trending with the dip in which differential movement of a torsional character occurred. There appears to have been no single direction of movement. Neither does any regular relation seem to exist between trend of fault and direction of displacement, nor between dip of fault and direction of displacement. It appears that displacement may be expected in any direction; that there is no constant relation between the direction of displacement and the dip or strike of a fault plane and that the amount of displacement proved underground rarely exceeds 150 feet and, except on innumerable minor faults, averages between 50 and 100 feet.

It is probable that important faults within this area have not yet been encountered underground. It is believed that in one or two instances these may include types not yet proved in Bingham, but evidence concerning them is difficult to obtain. Outside of this district, both to the north and south, considerable faulting probably occurred, and future stratigraphic study in connection with the general structure of the Oquirrh Range will probably reveal important and perhaps great faults.

Extensive developments made since the district was studied by Boutwell have revealed numerous faults and fissures that were then unknown and have led to some modifications of views concerning certain structures that were then only partly revealed; nevertheless, Boutwell's conclusions hold generally true for the more recently developed areas as well as for those that were accessible at the time of study.

ORE DEPOSITS.

The ore deposits of Bingham, as of most districts of the State, are of several types, classified by Boutwell as veins (including lodes), bed deposits, and disseminated deposits. Many deposits can be readily assigned to one type; others present characteristics of two types and their proper assignment may be difficult.

VEINS AND LODES.

Fissuring occurred at several periods; and the strong northeast-southwest fissures were the more important ore bearers, though some few fissures with other strikes were also ore bearing. (See p. 355.) These fissures cut all formations, and many of them show different characteristics in different types of rock.[1] Some fractures have produced zones of intensely crushed material in quartzite, irregular, anastomosing fissures in limestone, cleanly cut master fissures in igneous rocks, and may die out entirely in shaly material. The chemical composition of the different types of rock has also variably affected deposition by the ore-bearing solutions, and the character and size of the ore deposits have been governed accordingly.

The fissures in the intrusive rocks being relatively strong and clear cut and the wall rock relatively inert to the action of the solutions, the deposits are largely confined to the fissure filling. The more readily shattered quartzite has produced less definite fissures and consequently less well-defined ore bodies. The combined effect of a series of fissures rather than a clean break and a readily replaced rock have resulted in the strongest areas of mineralization in the limestone. Boutwell[2] says:

> Ore makes lean in siliceous rocks, more plentifully in porphyry, and largest and richest in limestone. In that portion of the galena fissure which lies in quartzite under the Jordan limestone lead and silver ore occur in relatively thin, small, tabular bodies, but in those portions of the same fissure which lie in calcareous rocks, ore occurs in relatively wider and thicker bodies, as in the Highland Boy limestone in a small way and in the Jordan limestone on a grand scale.

Veins in monzonite were found in the Last Chance, Nest, and in part of the Silver Shield where the wall rocks have been altered for a comparatively short distance and the ore is largely confined to the fissure. The alteration of the wall rock consists of a replacement of the original minerals by sericite, quartz, and secondary orthoclase. The ores are typically lead-silver but contain also gold, copper, and zinc.

Most of the silver-lead veins in the quartzite have proved less productive than those in the monzonite. Examples of such veins are to be found in the mines in Markham Gulch, the Silver Shield, and others. The copper veins in quartzite (like those of the Ohio Copper mine) might be placed with the fissure deposits, but as they are closely related to the disseminated deposits they may well be treated with these deposits.

Veins in limestone commonly enlarge along certain beddings and show a close relation to the bed deposits in limestones and may well be discussed with them.

Much of the ore in the fissures occurs in more or less clearly defined pod-shaped shoots which change in thickness from point to point both on the dip and strike.

[1] Boutwell, J. M., Economic geology of the Bingham mining district: U. S. Geol. Survey Prof. Paper 38, p. 126, 1905.

[2] Idem, p. 127.

BED DEPOSITS.

The bed deposits are confined to the limestone, the ore bodies forming as a replacement of the limestone and at many places preserving the structure to a marked degree. The ore-bearing fissures cut the limestone members, and at the intersection of beds especially susceptible to replacement the ore makes out laterally for considerable distances, forming bed deposits. The fissures themselves may or may not contain valuable ore deposits. In the more massive limestones some of the large ore bodies are associated with faults that have broken the limestone and have thus rendered it especially susceptible to replacement.

Generally, the large bodies of copper ore have formed along the bedding, as in the Highland Boy and Old Jordan mines, and the largest bodies of lead-silver ore occur both as replacement along the fissures and as bed deposits along certain beds in the limestone. Such bed deposits are present in the Yampa, Jordan, Commercial, and other limestones of the district.

Some of the important copper deposits of this character contain little lead, but the lead deposits contain copper, and some of them grade from ore in which lead and silver are the important metals to ore in which copper predominates.

The primary ore minerals in the copper deposits are pyrite, chalcopyrite, pyrrhotite, and minor amounts of arsenopyrite, bornite, and tetrahedrite. Specularite is locally abundant, as in portions of the Highland Boy mine. This specularite is in part rather strongly magnetic and doubtless contains some magnetite. The gangue minerals are quartz, residual carbonates, small amounts of garnet, and possibly other silicates.

The primary ore minerals of the lead-silver deposits are galena, pyrite, and minor sphalerite, chalcopyrite, and tetrahedrite in a gangue of residual carbonate and quartz.

Locally sericite is an important gangue mineral, especially in the deposits in the Bingham-New Haven mine, where it occurs as a soft talclike mineral with a greasy feel and silky luster.

DISSEMINATED DEPOSITS.

The disseminated deposits of the district are confined to the Bingham Canyon stock and to the immediately adjacent quartzite. The intrusive body is mineralized throughout its extent—much of it sufficiently so to be ore. In places the quartzite is similarly mineralized for a short distance, and along fissured zones for a considerable distance, from the contact.

This intrusive body and the quartzite have been cut by innumerable fissures that vary greatly in strike and dip and that cut the entire mass into small irregular blocks. So great has been this shattering that in many places it is difficult to break out a hand specimen that is not bounded by these fractures. The ore solutions passing along these fractures have altered the rock so that its original character can not usually be recognized. (See p. 351.) In the less-altered portions the mineralized rock consists largely of biotite resulting from the alteration of the dark minerals; sericite and quartz replacing the altered feldspars; and a granular groundmass of secondary quartz and orthoclase cut by veins of quartz and orthoclase. Scattered through both the veins and altered rock are grains of pyrite, chalcopyrite, and small amounts of molybdenite. A very little magnetic material, obtained from concentrates from the dark ore, appeared to be magnetite rather than pyrrhotite and possibly represents unaltered portions of the original magnetite.

The more highly altered rock is light colored and consists mainly of sericitized feldspar in a granular groundmass of secondary quartz and orthoclase, which in many places forms 50 to 75 per cent of the rock. Veins of quartz and orthoclase are also abundant, most of the larger ones being wholly of quartz, but many of the small ones containing considerable orthoclase. Grains of sulphide are disseminated through this as through the dark ore.

Under the microscope it is seen that there is every gradation between these types of ore, the lighter-colored material having been more highly altered. In the open pit both these types of ore are well exposed and are roughly separated by a prominent fault that cuts the ore body. The light-colored ore lies northwest of the fault on the hanging-wall side, and the dark ore southeast of it on the footwall side, though it is also present above the fault. At this locality the light-colored ore contains the most metal. In other parts of the ore body, however, both in the East Side workings and in the Boston Consolidated workings the

dark ore is said to be of equally good grade. In addition to the small quartz veins the ore body contains large bodies of rather fine grained vein quartz. As seen in the mine, this material rather closely resembles the mineralized quartzite, but under the microscope it appears as typical vein quartz and shows no evidence of clastic origin. The quartz grains contain many cavities filled with gas and liquid and commonly contain a small cube resembling salt and frequently a reddish mineral that is probably hematite. The size of these bodies strongly suggests that they are in part a complete replacement of monzonite rather than a filling of open spaces. Sulphides are disseminated through this vein quartz. Locally the monzonite contains light-green chloritic material containing abundant iron sulphide. Under the microscope this is seen to be composed of a green, slightly pleochroic hornblende and of chlorite, which in part at least results from the alteration of the hornblende. This appears to be an altered and mineralized basic rock, possibly a dike rock. If so, it must originally have been composed largely of hornblende, for no feldspar or secondary mineral from feldspar was noted in the specimen examined.

In addition to the fissuring which has affected the rocks containing the ore body over a large area more pronounced movements have occurred along definite lines and are shown in faults that are well exposed in the pit and on the stripped levels above the pit. Fissures showing more pronounced movement are also present in other parts of the mineralized area. In many places where these movements occurred in the monzonite they caused the formation of rather heavy gouge. In the quartzite the result was an area of crushed rock. As some of the gouge contained only sparse amounts of sulphide, and some of the original dark silicates are still preserved, it is evident that at least some of the movement occurred previous to the main period of mineralization and that the gouge prevented the free circulation of the ore-bearing solutions. In other places, however, gouges contain sulphides and were probably formed after the main mineralization. In the quartzite and in the monzonite, where the movement did not produce strong gouges, the zones of movement were favorable to the movement of ore solutions, and in many places the mineralization is greatest adjacent to them.

A few "veins" in the disseminated ores contain galena and sphalerite and some copper and iron sulphides. The fissures containing these have cut the ore and this mineralization is evidently later than the main copper mineralization.

The entire monzonite mass of Bingham Canyon and some of the adjacent quartzite has been mineralized. To what extent ore has been formed has not yet been fully demonstrated. The map (Pl. XXXV) shows the mineralized area as determined by development of the Utah Copper Co. to the close of 1916. At that time ore had been fully or partly developed over 226.3 acres. (See also Pl. XXXVI, p. 360.)

The depth to which ore extends is also as yet undetermined, though it has been shown that the tenor decreases with depth. At the close of 1916 the average thickness of the developed ore body was 524 feet. In the quartzite the Ohio Copper Co. has developed its ore body to the 500-foot level.

ALTERATION OF THE ORES.

Alteration of the deposits by surface solutions has been an important factor in producing the present condition of the ores, affecting both their character and their grade. It caused a material change in the metal content of the copper and gold ores, and it rendered large bodies of the lead-silver ores near the surface susceptible to the only metallurgic treatment practicable in early days.

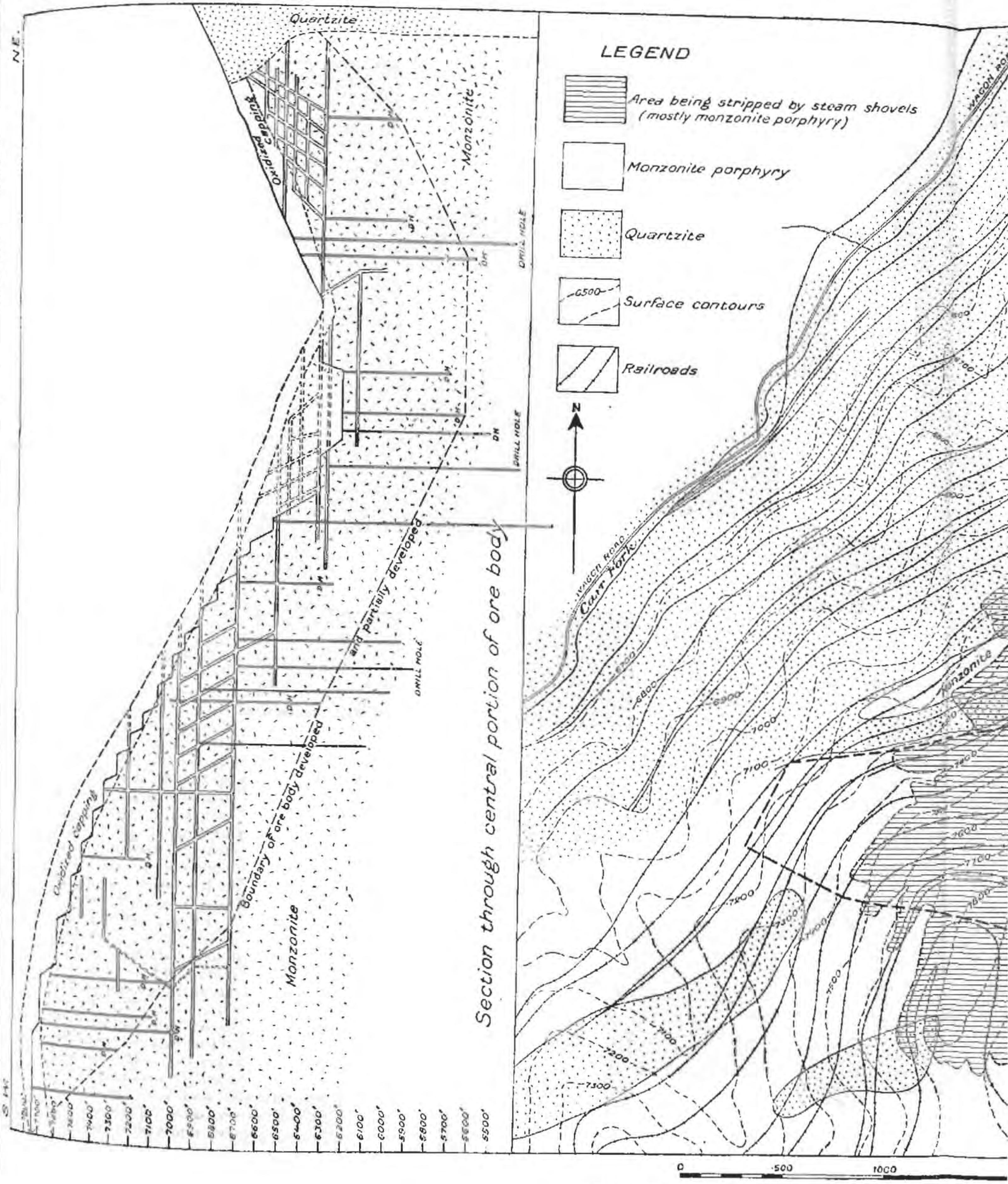
COPPER ORES.

The copper ores of the district fall into two general types—replacement deposits in limestone and disseminated deposits in monzonite and quartzite—in both of which secondary alteration has been important.

Replacement deposits.—Boutwell [1] says:

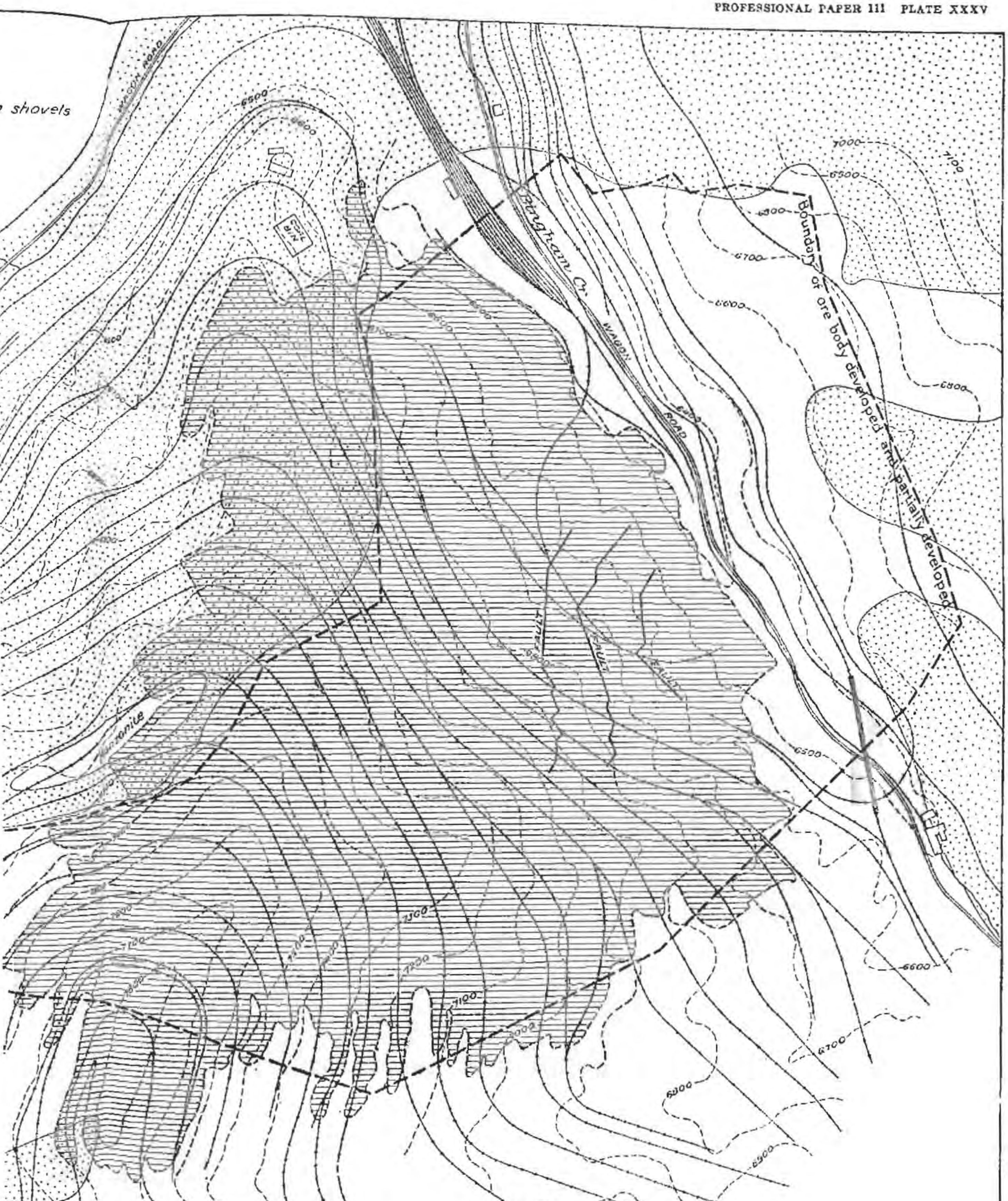
> The facts observed at Bingham show in general that carbonates, oxides, and native copper occur at the surface; that these pass into secondary sulphides, which in turn give way to primary sulphides in depth. Thus in the Commercial, Telegraph, Jordan, Highland Boy, Neptune, Fortune, Columbia, and other properties the surface portion of the shoots of copper-iron ore were made up of malachite and azurite, and, in the Commercial, of cuprite also. These gradually pass into sulphides in depth. In the

[1] Op. cit., p. 218.



GEOLOGIC MAP AND SECTION OF UTAH COPPER CO.'S MINING PR

Taken from company's annual report for 1915.



COPPER CO.'S MINING PROPERTY AT BINGHAM

Columbia cores of black sulphide occur within the green carbonate. In the Carpenter Shop tunnel, Telegraph mine, and Crown Point incline the carbonate ore gives way to sulphides, bands of the former forking down into the latter, becoming narrower in depth, and finally thinning out entirely to give way to sulphide.

Black sulphide marking the zone of sulphide enrichment, then, constitutes the body of the copper ore for a considerable distance in depth. * * * The thickness of the zone of oxides and carbonates is not so great as the thickness of the zone of black sulphides. The transition from the zone of oxidation to the zone of sulphide enrichment is gradual. It is to be seen in its earliest stage in the slight enrichment along fractures in primary sulphides, in hand specimens, and in thin sections showing various stages in its progress. * * * This enrichment may be observed to proceed gradually until, through the continued relative increase of the secondary sulphide and decrease of the primary, the entire mass of an ore body is made up of enriched high-grade black sulphide ore. This constitutes the so-called "black sulphide" ore, which is the richest copper ore in this camp. In its typical occurrence it is a loose, dry, dull granular black, earthy ore, intermingled with gray and grayish-black metallic scales and larger portions. This may frequently be seen inclosing cores of yellow sulphide and intimately associated with chalcopyrite and pyrite. Although this black ore varies in character somewhat, it is found on chemical examination of selected samples from several mines to consist chiefly of chalcocite (black sulphide of copper), tenorite (black oxide of copper), melaconite (massive earthy variety of the oxide of copper, tenorite), some tetrahedrite, and probably some enargite.

The stages of alteration and the general character above described are characteristic. Other types were noted, however. Thus in the Highland Boy alteration seems to have taken a somewhat different form; carbonates and oxides pass into a zone characterized by chalcopyrite, tarnished and coated with bornite and seamed with limonite. Specimens of Highland Boy ore from this zone show in thin sections under the microscope a granular, fractured mass of chalcopyrite traversed and rimmed about by seams of limonite. In the Northern Light, upper tunnel, in a corresponding zone, covellite coats chalcopyrite. And a specimen from the Kempton made up of pyrite crystals (possibly two generations) is coated with masses of chalcopyrite which in turn bear upon their surface crystals and coatings of tetrahedrite.

Below this zone of sulphide enrichment, low-grade cupriferous pyrite occurs. The passage out of this zone in depth is, like the entrance into it, gradual. Within the body of rich black ore nodules and grains of cupriferous pyrite occur, and in depth these become more numerous and pass into continuous bands which lead to the primary sulphides. The transition from secondary to primary sulphides, begun in this way, progresses by continued decrease of secondary and reciprocal increase of primary sulphides. Thus the lowest workings in the Commercial and Telegraph are still in a zone of sulphide enrichment, in the Jordan below the water level, and in the Highland Boy a zone of pyrite has been encountered, which shows a decrease in the copper content.

Since the above was written more depth has been attained in some of the deposits, notably in the Highland Boy mine, where ore bodies have been developed to the thirteenth level. On the lower levels the mineralized bodies, though large, are, in large part, of too low grade to be mined at a profit under average conditions. The content shows a decrease in gold and silver as well as in copper.

Disseminated ores.—The alteration of the disseminated ores is in general similar to that of the replacement deposits, the important difference being that less of the copper has been left in the oxidized zone as carbonates and oxides, and more of it has been carried to lower levels and precipitated in the zone of sulphide enrichment.

The sulphides have been largely oxidized for a varying distance below the surface. At the surface some of the iron is usually present in limonite or some closely allied mineral, but some of it has been removed, the iron in limonite apparently not equaling that in the the primary ore. At the surface almost all of the copper has been removed, especially from the higher elevations. Below the surface and in the lower areas bordering Bingham Canyon more iron and considerable copper still remain, the iron in part as hydrous oxide and possibly in part as ferric sulphate, and the copper as carbonate and in places as sulphides. In part of the area the oxidized capping contains sufficient copper to be classed as ore, and a plant for the treatment of this class of ore by a leaching process began operations in 1917.

The silicate minerals of the ore have undergone remarkably little alteration. No analyses of the capping have been made, but microscopic study indicates that the orthoclase and sericite have been but slightly altered, though most of the biotite is distinctly bleached. Weathering would naturally break down the silicates, removing the potassium and magnesium and producing kaolin and allied minerals, but the microscopic study reveals no important alteration of this character except in the biotite.

In general it may be said that the alteration of the sulphides first resulted in the formation of iron and copper sulphates. Then the iron sulphate in part oxidized to ferric sulphate, in part possibly combined with other elements to

form relatively stable sulphate minerals, such as jarosite, and in part broke down into ferric oxide and sulphuric acid.

In part both the copper and iron were removed as sulphates in solution. Part of the copper was temporarily fixed as the relatively stable carbonates.

The ferric sulphates if formed are only relatively stable and eventually break down, possibly into ferric oxide and sulphuric acid, which would act on the copper carbonates present and permit these to be removed in solution. Thus in the early stages of oxidation the "capping" would contain considerable copper, while in the final stages this would be largely removed. This process is of course constantly working downward, so that in reality the secondary sulphides are also involved in the oxidation process.

Along certain channels especially favorable to the circulation of solutions, notably in the fissures in the quartzite, oxidation has resulted in the formation of considerable amounts of oxide of copper and some of native metal.

The thickness of the oxidized zone is variable, but in general is greatest at the greatest elevation and least at the lower levels, though of course deeper along channels favorable to circulation. Thus in 1912 the average thickness of capping over the original Utah copper group, which lies at relatively low levels adjacent to Bingham Canyon, was estimated at 84 feet, and the average thickness in the Boston Consolidated and Pay Roll groups, at higher elevations, at 134 and 206 feet, respectively. The average thickness for the entire ore body as developed to the close of 1914 was 115 feet.

Underlying the zone of oxidation is the zone of secondary sulphides. In this zone the primary sulphides, pyrite, and chalcopyrite, and possibly some bornite, have been partly or wholly replaced by the copper sulphides covellite and chalcocite. A little bornite is present in the ore. In some places this appears to be a replacement of other sulphides, and in other places its relations strongly point to its primary origin.

It has been generally considered that the principal secondary sulphide of the deposit is chalcocite, but an examination of specimens from different parts of the ore body revealed a surprisingly large amount of covellite. Many of the fine grains in which much of the mineral occurs can be determined as covellite or chalcocite with difficulty without a polished section, but covellite appears to be the more abundant. Much sooty material and the surfaces of many grains are dark and look like chalcocite, but a large proportion of the secondary sulphide shows the deep indigo blue of covellite, and this can usually be seen with a lens in the hand specimen by scraping the surface of the grains. On the other hand, specimens that appear to contain abundant covellite when examined in polished sections are seen to contain abundant chalcocite covered by a very thin coating of covellite. Beeson states that covellite is the more abundant secondary sulphide in the higher portions of the ore body, but that chalcocite becomes increasingly abundant near the bottom of the canyon.

The change from the zone of the yellow oxidized ore to that of sulphide enrichment is usually very sharp, the "capping" resting on the ore with not more than a few inches or at most a few feet of transition. The change in metal content, however, is not usually so sudden. The metal in the "capping" not being susceptible to satisfactory recovery until recently, however, has made the line between ore and waste much more definite than is indicated by the metal content.

Underlying the zone of secondary sulphides is that of primary sulphides. Much of the material that contains little covellite or chalcocite is ore, but it decreases in tenor with increase in depth. This naturally suggests enrichment by the addition of copper in the form of chalcopyrite, and this seems to be the theory held by those most familiar with the ore deposit. Beeson has shown that some of the material that appears to be chalcopyrite is only a thin film of that mineral covering covellite or chalcocite, all three of the copper sulphides being of secondary origin.

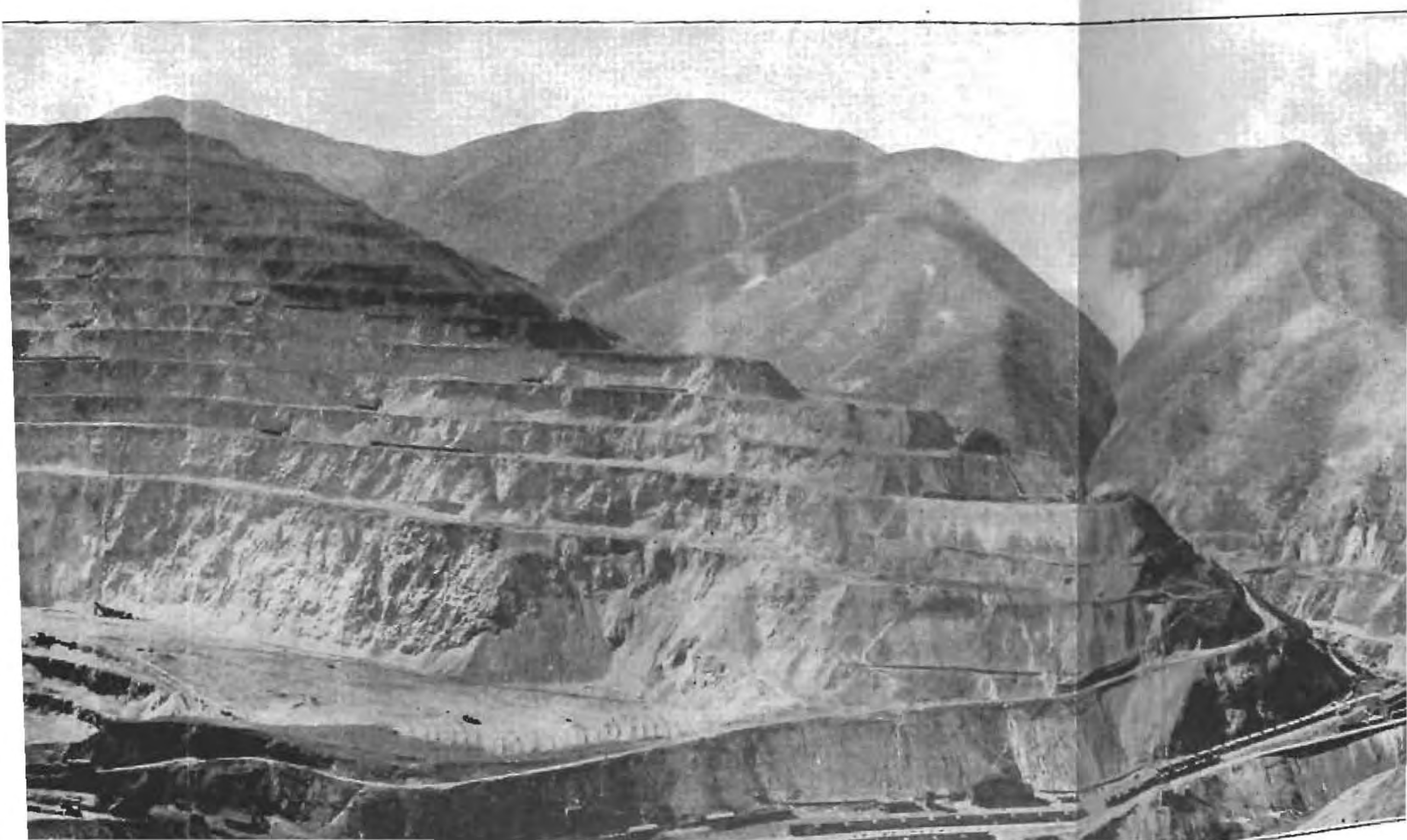
The cross section of the ore body (see Pl. XXXV) shows that the ore goes deepest in high ground, where oxidation is greatest. Development also goes deepest in this part of the ore body, however, and until greater depth has been attained near the canyon bottom it can not be stated that the ore is not equally thick there. At the close of 1916 the average thickness of the commercial ore as developed in the property of the Utah Copper Co. was 524 feet.

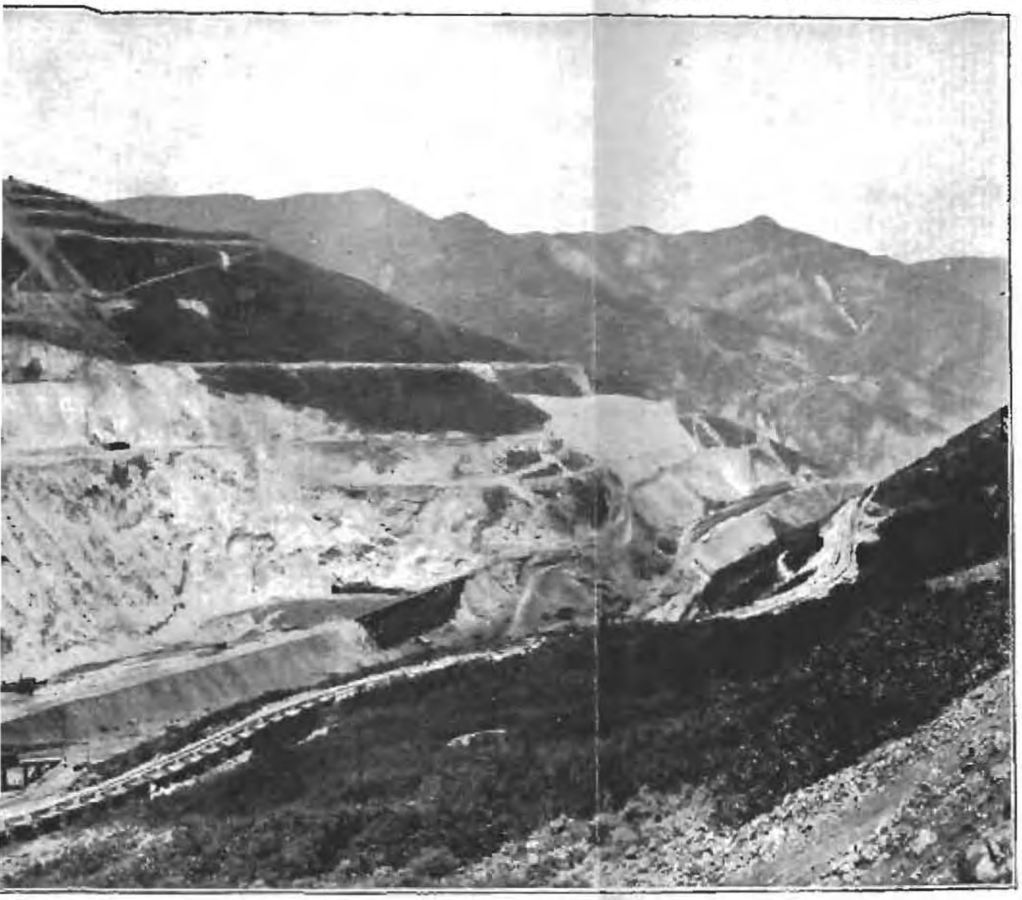
A. VIEW IN 1908, WHEN ORIGINAL O

B. VIEW IN 1915, AFTER STRIPPING IS

ORE DEPOSITS

VIEW IN 1908, WHEN ORIGINAL OUTLINE OF HILL WAS STILL APPARENT.





APPARENT.

CH ORE MINED.

BINGHAM CANYON

LEAD-SILVER ORES.

Galena, which forms the most important primary mineral of the lead-silver ores, is relatively resistant to weathering agencies. Consequently, the alteration of these ores has proceeded slowly, and many residual fragments of galena remain in the ore even near the outcrop. Tetrahedrite, which is an important silver-bearing mineral, is more readily attacked. The final product of alteration of the galena is ordinarily the carbonate, cerusite, though the sulphate, anglesite, commonly forms as an intermediate product and more complex sulphates are probably also formed. The oxidized lead-silver ore bodies show no marked migration of the lead or silver, though they have been somewhat enriched and were rendered much more favorable to the early treatment by the removal of other elements.

GOLD ORES.

The gold ores of the district have resulted from the alteration of auriferous pyrite bodies in the limestone. They were worked at numerous localities in the early days, but, although gold was obtained from some of them, none have proved very productive.

Oxidation of the pyrite freed the gold and concentrated it to some extent. Boutwell[1] described the process as follows:

> These changes probably comprise (a) the attack on gold-bearing pyrite, iron sulphide, by oxygen of surface waters, resulting in the formation of ferrous sulphate and consequent freedom of gold content; (b) the breaking up of iron sulphate into sulphuric acid, limonite, and water; (c) the passage of the acid, water, and limonite downward, leaving the gold content in the resulting cavity, and thus the accomplishment of the relative concentration of free gold.

GENESIS OF THE ORES.

The ores of the district have probably been formed during one general period of mineralization and have had a common origin. The differences in the character of the ores are probably due to differences in the physical conditions under which they formed and possibly to slightly different times of formation during the general period of ore deposition.

The intimate association of the ore deposits with the intrusive rocks leaves little doubt of their close genetic relations. That the main ore deposition took place after the intrusion is evinced by the fact that deposits occur in the intrusive rocks as well as in the adjacent rocks. In the limestones the ore deposits are associated with fissures more closely than with dikes, but dikes of monzonite porphyry are rarely if ever far distant from a well-mineralized area in the limestone.

The general order of mineralization was probably about as follows: The intrusion of the monzonite bodies and the accompanying fissuring and alteration of the adjacent sediments; the cooling and crystallization of the monzonite and its fissuring from shrinkage and adjustment of stresses; the passage along the fissures both in the monzonite and in the adjacent sediments of solutions of deep-seated origin that altered the rocks and deposited the metals.

Highly heated solutions deposited gold-copper ores and less highly heated ones lead, silver, and zinc. Lead-zinc veins occur in fissures in the disseminated ore, and were evidently deposited later than copper. This, however, is not believed to indicate that the lead ores as a whole were later than the copper ores, but rather that at the time the copper ores were deposited physical conditions in those places were not favorable to the deposit of lead-zinc ores. When the temperature and possibly the pressure in this zone had been reduced lead-zinc ores could and did deposit. Fissuring and faulting continued after the deposition of the ores, and finally the ores were altered by surface solutions.

PLACER DEPOSITS.

Auriferous gravels were the earliest deposits worked in the district, and in early days were the source of considerable gold. The placers occur as bench and stream gravels in Bingham Canyon and its tributaries. Boutwell[2] summarizes their history as follows:

> In post-Carboniferous time the Oquirrh Range gradually emerged above water level and grew northward. Streams flowed northward down its slopes and began the work which Bingham Creek and its tributaries are to-day carrying on. That work consisted of wearing down the surface, cutting valleys, and transporting downstream the product of that erosion. * * *
>
> This generally continuous dissection has been made possible by a broad uplift with slight eastward tilting of the entire region accomplished during definite stages which were characterized by elevation followed by quiescence

[1] Boutwell, J. M., op. cit., p. 228.

[2] Idem, p. 348.

and degradation, and by subsequent aggradation which may be due to slight depression. * * *

During these land movements the activity of the erosive agents has varied accordantly. At an early date auriferous gravel was formed by the erosion of gold-bearing ore shoots in limestones and of igneous and probably sedimentary auriferous rocks. Portions deposited in stream beds were subsequently left as benches by further stream incision. Repeated deposition and subsequent dissection have produced a series of high bench and rim deposits of auriferous gravel. The principal deposits of auriferous gravel were laid down (1) at the close of the erosion stage, marked by the mature slopes, and (2) after the close of the cutting of the recent canyon and the succeeding depression. The former is recorded by the Argonaut and Dixon bench gravels, and the latter by the wedge of creek gravels. Each removal of gravel and its included pay from higher to lower levels, as well as each transportation downstream, has acted further to sort and to concentrate the gold. Thus the present creek gravels, including their eastern continuation, include all the gold released from bedrock from earliest to latest time, except the relatively small per cent left on the benches and that removed by man. The present recent dissection of the creek gravels and any normal succession of activities which may follow will continue this process of natural concentration of the placer gold.

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RUSH VALLEY AND OPHIR DISTRICTS.

MINING HISTORY AND PRODUCTION.

By V. C. HEIKES.

LOCATION OF THE DISTRICTS.

The Rush Valley and Ophir districts, in Tooele County, were formed June 12, 1864, and August 6, 1870, respectively. These districts were originally part of the West Mountain (Bingham) district. In 1863 they comprised the mining sections now known as Camp Floyd (Mercur), East and Dry Canyon, Tintic, and Tooele districts. A narrow-gage railroad, the Utah & Nevada Railway, was constructed in the seventies from Salt Lake City to Stockton, and in 1905 this was made broad gage and became a part of the Los Angeles & Salt Lake Railroad. In 1912 a branch of this railroad was completed from St. Johns to Ophir, doing away with a wagon haul of about 16 miles.

HISTORY.

RUSH VALLEY DISTRICT.

Rush Lake, from which Rush Valley takes its name, is a remnant of Lake Bonneville.[1] In 1855 it was included in a military reservation laid out by Lieut. E. J. Steptoe for the purpose of securing to the military post at Camp Floyd the meadow and pasturage about the lake shore. Gilbert says:[1]

> The land surveys in the valley in 1856 did not include the military reservation but showed the existence upon it of a lake. According to Gen. P. E. Connor, who succeeded Col. Steptoe in 1862, there was then only a small

[1] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, p. 228, 1890.

pond, the remainder of the lake bed being occupied by meadow land. In 1865 the water began to increase, the greatest height being attained in 1876 or 1877, since which time it has subsided. The rise of the water submerged the meadow land and rendered the reservation useless for its original purpose. It was therefore officially relinquished by the War Department in 1869. In 1872, the water being near its highest stage, the lake was surveyed in connection with the surrounding country by one of the parties of the Wheeler survey and the length was determined to be 4½ miles. In 1880, when the lake was visited by the writer, it was said by residents to have shrunken to half its maximum size.

The reservation [1] for the military post was sold by the Government in 1861 and was repurchased in 1864 by Gen. Conner, who occupied it with a portion of the California and Nevada volunteers then stationed at Camp Douglas, near Salt Lake. The town of Stockton was surveyed and organized in March, 1864, and made a military post known as "Camp Relief."

The Rush Valley deposits were discovered [2] in April, 1864, by some members of Company L, Second Cavalry, California Volunteers, who were guarding stock on the reservation. Assays from the first ledges discovered proved to be rich in silver, and a mining district was organized. The first house was built in Stockton during July, 1864, and in 1866 the town had 40 families and 400 inhabitants.

Soon after the organization of the district, Lieut. James Finnerty erected a small trial furnace to test ore, and about the same time a large one was built by the Rush Valley Furnace & Smelting Co. Both were only partly successful, owing to the imperfect quality of the fire brick used. Subsequently Lieut. Finnerty built a second furnace and ran it with good results for a number of weeks, turning out a quantity of metal from surface ore. Attempts to separate the gold and silver from lead by means of the "Lyon process," which was used to smelt the ores of the Perigo mine [3] in Gilpin County, Colo., were made by the Knickerbocker & Argenta Mining & Smelting Co. but were not successful, and the mines were abandoned in the later part of 1865. The Monheim & Johnson Co.[4] completed a blast furnace in 1866 to treat ores from the Delmonte and Great Basin ledges; J. W. Gibson in the same year erected and put in operation a smelter with a capacity of 600 pounds a day. The Union Vedette says:

> Nine runs have been made of a hundred pounds each and 300 pounds of metal was obtained, some of which has been brought to this city and assayed by Bohm & Molitor and gives $228 in silver per ton. The remainder is nearly pure lead. * * *

Soon after the close of the Civil War the volunteers at Camp Douglas were disbanded, being relieved by regular troops from the east. Most of those who had mining prospects, after meeting and amending the by-laws so as to make claims perpetually valid which had but little work done on them, left the Territory to seek employment elsewhere. This action, which prevented all subsequent relocation of the same ground, greatly retarded and in fact prevented for some years the development of the Rush Valley district.[5]

The mining claims of the district center in the foothills 1 to 2 miles due east of Stockton, and extend about 2 miles north and a like distance south.

The early conditions of mining, reviewed in brief detail by Sloan [6] in 1873, are of interest. Sloan says in part:

> About midway the district and 1 mile from Stockton is a heavy outcrop of a belt of blue limestone running east and west. Dipping under this is a well-defined vein, 3 feet in width, carrying argentiferous galena, mixed with iron ocher. The following mines are on this belt, which extends about a mile in length. On the east end is the first discovery in the district, called the Lincoln, now known as the Argent; developed by shaft 100 feet in depth and one 50 feet; ore 50 per cent lead and 40 ounces silver to the ton, though one lot yielded 60 per cent lead and 20 ounces silver. * * *
>
> Adjoining west is the Tucson * * *. One lot of ore yielded 60 per cent lead and 87 ounces silver to the ton.
>
> The formation is somewhat broken west of the Tucson, but it is evident the Bolivia is on the same vein; it is opened by a shaft over 100 feet in depth, and there is much ore on the dump * * *.
>
> West from the Bolivia is the Silver King, from which was shipped the first carload of galena ore sent from Utah; * * * Average of ore in value about 50 per cent lead and 40 ounces silver to the ton.
>
> Toward the north part of the district is the Southport; quartzite vein carrying galena and carbonates in large quantities; course of vein, north and south; * * * vein about 3 feet in width * * *. The St. Patrick, opened by an incline of 100 feet. This mine at one time yielded a large amount of ore.

[1] Union Vedette, published at Camp Douglas, Salt Lake City, Apr. 22, 1864.

[2] Idem, Apr. 2, 1866.

[3] Lyon process and Perigo mines, Colo.: Union Vedette, Jan. 27 and July 18, 1866.

[4] Union Vedette, Apr. 2, 1866.

[5] Whitney's History of Utah, Salt Lake City, Utah, vol. 2, pp. 271–275, 1893.

[6] Sloan, E. L., Salt Lake City Directory, 1874, pp. 148–151.

Up Quandary gulch, one-fourth of a mile from Silver Spring, is the Quandary lode, developed by a shaft over 100 feet in depth, with levels run therefrom.

Opposite the gulch from the Quandary, is the Great Basin lode, opened by tunnel 100 feet, and shaft 150 feet; has produced high-grade ore.

A short distance above the Quandary up the gulch is the first extension north of the Great Central lode, a well-defined, true fissure vein, in quartzite, running north and south; ore about 50 per cent lead and $150 per ton of silver.

North from the Quandary, on the top of the hill, is the mine Our Fritz, with shaft 100 feet in ore all the way, which assays about 60 per cent lead and $94 in silver to the ton; * * *.

The First National (formerly Flora Temple) is a well-developed mine with a shaft over 100 feet; strong vein and good body of ore.

Many of the claims, which were worked in the early days as individual properties, now form part of groups owned by the Bullion Coalition (formerly Honerine), Galena King, New Stockton, Black Diamond, Cyclone, Silver Coin, and Southport.

The Great Basin claim, which later became the property of the Honerine, also known as the National, was included in the group of 77 patented mining claims and fractions transferred to the Bullion Coalition Mines Co. in 1910. The property is opened by an adit 13,000 feet long. The total output of the Honerine and its predecessors is reported [1] to have been 80,000 tons of ore valued at $1,250,000 to the end of 1889. At that time there were 11,500 feet of openings and the greatest depth was 660 feet. A large concentrator was in operation and has been worked intermittently up to the end of 1913. Between 1890 and 1901 there appears to have been very little ore produced from the Honerine mines; at least, the United States Geological Survey is not in possession of the records.

The Jacobs smelter, built at Stockton in 1872, consisted of three vertical blast furnaces and used ores from the Fourth of July and Kearsarge mines near Ophir. The Fourth of July was owned by Lilly, Leisenring & Co., of Philadelphia, who were owners of the Jacobs works. In 1879 the Great Basin concentrator, consisting of jigs, was installed in an extension building covering the Jacobs furnaces, and in 1880 [2] was milling 100 tons of ore a day, producing 20 tons of concentrate. One stack of the Jacobs smelter was in operation at the same time, reducing about 25 tons of ore a day and turning out about 5½ tons of bullion assaying 100 ounces of silver per ton.

The Chicago smelter,[3] long ago dismantled, was built on the east shore of Rush Lake near Stockton, in August, 1873. Its last operation was recorded in 1880. Huntley [4] says:

> The Chicago smelter is at Slagtown, on the eastern shore of Rush Lake, about 2 miles south of Stockton. It was built in 1873 by the Chicago Silver Mining Co., an English company, which once owned the Chicago and the Queen of the Hills mines in Dry Canyon. It ran quite steadily until 1877. It was then idle until leased in 1879 to Mr. Brooks, who ran it until the autumn of 1880, when it was shut down.

The Carson & Buzzo smelting works, about half a mile south of the Chicago, erected two vertical blast furnaces in March, 1873, and commenced operations shortly afterward. The ores used were obtained chiefly from the Utah-Queen mine, owned by the same interests. Later Carson & Buzzo erected extensive reduction works at West Jordan.

The Waterman smelting works were the most important and were operated at a later date (1886) than any in the vicinity. Huntley [4] says:

> The first furnace in the territory, an unsuccessful reverberatory, was erected here in 1864 by Gen. Connor and his officers. It was bought in 1871 or 1872 by Mr. I. S. Waterman. * * * This smelter ran quite steadily for several years on Hidden Treasure ore and some custom rock, but not profitably. * * * During the four years ending April 1, 1878, 26,270 tons of ore were smelted, and yielded 8,312 tons of base bullion, which sold for $109.64 per ton, or $911,350. During this time 3,300 tons of flue dust were caught, which assayed from 36 to 57 per cent lead and from 13 to 35 ounces silver.

The production of the Rush Valley district during its early activity is hard to ascertain. No complete records are available, and estimates from the district have been combined with those collected for the Ophir district. Since 1901 the figures have been collected by the United States Geological Survey.

[1] Jones, M. E., Internal commerce of the United States, p. 892, 1890.

[2] Rept. Director of Mint upon production of precious metals, 1880, p. 130.

[3] Cameron, J. E., jr., M. E., Mines and furnaces of Ophir, Dry Canyon, and Rush Valley districts, Utah Mining Gazette, June 6, 1874.

[4] Precious metals: Tenth Census U. S., vol. 13, p. 450, 1885.

Metals produced in the Rush Valley mining district, 1901–1917.

Year.	Ore (short tons).	Gold.		Silver.		Copper.		Lead.		Recoverable zinc.		Total value.
		Fine ounces.	Value.	Fine ounces.	Value.	Pounds.	Value.	Pounds.	Value.	Pounds.	Value.	
1901	[a] 400	34.54	$714	6,618	$3,971	....	....	[a] 200,000	$8,600	....	....	$13,285
1902	496	64.00	1,323	7,479	3,964	....	....	250,651	10,271	....	....	15,558
1903	142	4.69	97	1,211	654	....	....	27,009	1,134	....	....	1,885
1904	[b] 44,145	292.99	6,056	176,510	101,052	5,248	$656	11,978,448	524,057	....	....	631,821
1905	[b] 40,431	322.00	6,656	56,025	33,839	413	65	3,499,020	155,419	....	....	195,979
1906	[b c] 37,409	398.88	8,246	95,861	64,227	3,858	745	4,982,872	284,024	....	....	357,242
1907	[b] 48,318	324.43	6,707	130,487	86,121	318	63	6,622,042	350,968	....	....	443,859
1908	[b] 2,602	14.70	304	31,386	16,635	5,779	763	1,676,217	70,401	....	....	88,103
1909	[b] 5,627	21.48	444	24,096	12,530	1,781	232	1,213,266	52,170	....	....	65,376
1910	[b] 1,981	27.32	565	15,888	8,580	10,354	1,315	965,146	42,466	....	....	52,926
1911	10,107	477.38	9,868	102,863	54,517	12,689	1,586	4,969,476	223,626	....	....	289,597
1912	[d] 45,453	1,141.31	23,593	261,588	160,877	319,859	52,777	10,971,278	493,708	....	....	730,955
1913	[b e] 14,897	585.09	12,094	128,675	77,720	29,521	4,576	4,619,259	203,247	9,019	$505	298,142
1914	19,332	420.18	8,686	108,979	60,265	21,680	2,883	3,791,497	147,868	69,582	3,549	223,251
1915	19,780	398.15	8,230	90,666	45,968	37,899	6,683	4,151,151	195,104	99,034	12,280	268,215
1916	24,710	439.31	9,081	108,841	71,617	118,943	29,260	5,413,042	373,500	136,615	18,306	501,764
1917	10,713	708.53	14,647	79,797	65,753	43,335	11,830	3,315,077	285,097	56,490	5,762	383,089
	326,543	5,674.98	117,311	1,426,970	868,290	611,677	113,384	68,645,451	3,421,660	370,740	40,402	4,561,047

[a] Estimated. [b] Partly milling ore, concentrates produced. [c] Mostly old tailings. [d] Includes 27,647 tons of old slag from early smelting operations. [e] Includes 2,049 tons of old tailings and slag.

OPHIR DISTRICT.

The ores in the Ophir district were discovered in 1865.[1] Treasure Hill, in East Canyon, had long been a sacred spot whither the Indians repaired each year to hold councils and to obtain metal for bullets. Soldiers of Gen. Connor's command, attracted by these legends, located a cropping of lead ore at the St. Louis lode, now known as the Hidden Treasure mine. Other locations soon followed, among which were the Pocatello, made near where the Velocipede was afterward located on Silver Shield Hill, and the famous Wild Delirium at the foot of Ophir Hill.

Very little work was done on the locations until 1870, when the excitement caused by the rich developments in the Little Cottonwood district stimulated prospecting. In the summer of 1870, A. W. Moore laid out the town of Ophir, and a new mining district was organized. In August, 1870, horn silver was found on Silverado Hill, perhaps by W. T. Barbee,[2] and the Silveropolis, Chloride Point, Shamrock, and other claims were located. A few days after the discovery of the Silveropolis lode, the Mountain Lion, Silver Chief, Mountain Tiger, Rockwell, and other locations were made on Lion Hill.

The nearest railroad point to Ophir in 1872 was the Utah Southern Railroad, which terminated at Lehi and was reached via Lewiston and Fairfield. In 1872 the Pioneer mill, belonging to Walker Bros., was treating 25 to 30 tons of ore a day, using a Blake crusher, fifteen 750-pound stamps, an Aikin furnace, six Wheeler pans, and three settlers. There were three smelting plants in the vicinity.[3] Huntley[4] says:

The Ophir district * * * includes several canyons and ridges on the western slope of the Oquirrh Range, the principal of which are Ophir or East Canyon and Dry Canyon, containing the mining camps of Ophir City and Jacob City, respectively. There was much excitement in 1872, 1873, and 1874, since which time the camp has gradually declined. At the period under review there were not 50 persons where formerly there were 1,000. The records showed about 2,500 locations, on not over 150 of which was assessment work kept up. * * *

Much of the ore of the district has been very rich, the assays sometimes averaging among the hundreds, and even thousands. In East Canyon the ore was usually a very siliceous or milling ore; but that from Dry Canyon contained much lead and was smelted. This district has produced many million dollars; how many can never be known, as the mine owners of the early days are scattered over the Pacific coast. Many local attempts to treat the ores were made in East Canyon, but were for the most part failures. The works remaining at the period under review were the buildings of the Pioneer and the Baltic mills, and the Cleveland and the New Jersey arrastres.

The Pioneer mill was built in 1871 by Walker Bros., of Salt Lake City, to work ore from the Zella group and other mines on Lion Hill. It was a 20 stamp dry-crushing silver mill with an Aiken furnace, and cost about $75,000. Many hundred thousand dollars in bullion were extracted. The machinery was moved to Butte, Mont., several years ago. The Baltic mill was a small 5-stamp mill, with two pans and a settler, and was run by a turbine water wheel. It was not worked regularly. The arrastres * * * were fairly successful, owing to the high-grade and free nature of the ore. Latterly, ore has been shipped to Salt Lake City or to the Stockton smelters. * * *

The following works were built in early times but had been moved away or were in ruins: Pioneer smelter, built in 1871; probably produced 125 tons of bullion. Ophir smelter, built in 1872; produced but little. Faucett smelter, built in 1872; small product. Brevoort mill, built in 1872; two stamps. Enterprise mill, built in 1873; five stamps. One mill (name unknown), built in 1874; five stamps. Also several small arrastres run by water wheels.

The Zella group [East Canyon and vicinity] comprises the Zella, Mountain Tiger, Silver Chief, and Rockwell, patented, and several others unpatented. It is situated on the western side and near the summit of Lion Hill. The mines were discovered in the autumn of 1870 and sold to Walker Bros. in 1871, who worked them until 1876, since which time they have been leased. The ore outcropped in two places, the croppings assaying $200 per ton. Three large bodies and several smaller ones were found about 20 feet below the surface. * * * The total product of this group was estimated at $750,000.

The principal work [on the Monarch group] was done in 1875 and 1876. Since then the property has been leased. * * * It is said that the ore averages 130 ounces silver per ton with from nothing to $8 in gold, and from nothing to 12 per cent of lead. Much of it, however, would assay upward of $500. * * * The total product to the close of the census year was $117,500.

The Douglas mine was located in 1871, and was worked principally in 1875, 1876, and 1877. It has been idle or leased since. It is situated near the western summit of Lion Hill, about a mile southeast of Ophir City. It is near the Monarch group, which it greatly resembles in gangue and ore. * * * The total product is said to be at least 1,000 tons of 100-ounce ore.

The Trace group was located in August, 1878, and worked in a small way since by the owners. * * * The total product to the end of the census year was $11,565.

The other mines of East Canyon and vicinity are:

[1] Wells, Spicer, Utah Mining Gazette, Jan. 7, 1874.

[2] Huntley, D. B., Precious metals: Tenth Census U. S., vol. 13, p. 177, 1885.

[3] Wheeler, G. M., U. S. Geog. Surveys W. 100th Mer. Prog. Rept., pp. 14-20, 1872.

[4] Op. cit., pp. 450-454.

Mines of East Canyon and vicinity.

Mines.	Total length of openings.	Total product.	Remarks.
	Feet.		
Exchange and Sunnyside.	1,000	$80,000	
Lion	1,000	120,000	
Chlorido Point and others on Silveropolis Hill.	....	....	Several hundred feet of cuttings; produced many thousands in early days.
Miner's Delight group.	a 300	....	Ore assays 19 ounces silver and 11 to 14 per cent lead; sells for $7 per ton; total product, many thousand tons; 1,200 tons extracted in census year.
Bonanza	....	....	Has produced considerable ore.
Cleveland Mining Co.	1,430	100,000	Ore assays $150 to $1,000 per ton.
San Joaquin	750	35,000	Ore assays $100 to $400 per ton.
Poorman	b 500	Small.	Little ore ever shipped.
Buckhorn	a 300	....	Ore assays 20 ounces silver, 35 per cent lead; much ore formerly produced.
Mountain Gem and Antelope.	1,000	....	Surface ore assays 20 ounces silver, 30 per cent lead; several thousand tons shipped in 1877 and 1878.
California	....	....	Ore assays 25 ounces silver, 55 per cent lead.

a Incline; also other cuttings.
b Drifts; also shaft of several hundred feet.

The Hidden Treasure mine [Dry Canyon] is situated on a steep hillside above and three-quarters of a mile northeast of Jacob City. It was located in 1865 as the St. Louis lode by Gen. Connor's soldiers, who had been told by Indians of the outcropping boulders of galena. Little work was done until April, 1870, when it was relocated as the Hidden Treasure. The mine has been extensively but irregularly worked since 1872. * * * The ore assays from 15 to 40 ounces silver and 20 to 50 per cent lead. * * * During the four years ending April 1, 1878, 28,400 tons were mined. Most of this was smelted at the Waterman smelter at Stockton. The cash received for this amount of ore, whether sold as ore or as bullion, was $938,700. Several thousand tons of ore were produced prior to 1874.

The Chicago mine was located in 1871, and sold to an English company soon afterward. The mine was worked vigorously for several years but has been idle since 1876. * * * The mine produced considerably over 12,000 tons of ore. This company owns the Chicago smelter, and when the mine failed bought the Queen of the Hill, Falvilla, and Mahogany locations. They were located in 1870-71, and were worked extensively between 1873 and 1877 but very little since. Shortly after the purchase the Chicago company came to the fault and failed. * * * The product of these mines * * * was probably over $1,000,000.

The Mono mine is situated half a mile south of Jacob City. It was discovered in the autumn of 1871, and was owned in the early days by Gisborn, Embody, Heaton & Miller. It was worked vigorously by them until 1875, when Gisborn bought the remaining two-thirds interest for $400,000, mortgaging the whole to eastern capitalists for the money. About three months after the sale a fault was found, or the ore chute "pinched," and only a small prospecting force was employed until June, 1879, since which time it has been idle. * * * The total product was not known, even by the original owners, as they divided the proceeds after the sale of each lot. By one it was placed somewhat over and by another somewhat under $1,000,000.

The Mono tunnel site is in the ravine 800 feet below the Mono mine. Work was begun in 1872 or 1873. The tunnel is about 1,100 feet in length. * * *

The Kearsarge mine, located half a mile west of Jacob City, was discovered in 1871. * * * The total product was unknown, perhaps $1,000,000. * * * A few hundred tons of 40-ounce ore were produced.

The Deseret group * * * were located in 1870-71. Work on them was begun in 1874 and discontinued January 1, 1879. * * * The total production of the group was estimated at $30,000.

The other mines of Dry Canyon are:

Mines of Dry Canyon.

Mines.	Total length of openings.	Total product.	Remarks.
	Feet.		
Wandering Jew	4,200	....	A few hundred tons of 30-ounce silver and 35 per cent lead ore extracted.
Utah Queen	900	....	Large amount of ore extracted.
Sacramento	800	....	Considerable ore taken out formerly.
Mountain Savage and I. X. L.	1,000	a 2,100	Ore assays 40 ounces silver and 25 per cent lead.
Emporia	1,600	$30,000	
Fourth of July	b 440	a 1,000	Ore assays 30 ounces silver and 35 per cent lead.
Evening Star	350	....	Some good grade ore shipped.
Magnolia	....	....	Several hundred feet of incline and drifts; much money spent, little received.
Rattler	....	....	Few hundred feet of work done.
Brooklyn	....	....	Do.
Elgin	....	....	
Noyes	....	....	

a Tons. b Incline; also other cuttings.

METAL CONTENT OF THE ORES.

DRY OR SILICEOUS ORES.

The dry or siliceous ores shipped to smelters from the Ophir and Rush Valley districts comprise gold and silver ores carrying copper and lead in amounts too small to be of value. The mines, named in order, according to the frequency of their shipments in the last decade, were the Chloride Point, Lion Hill, Buffalo, Queen of the Hills, Hidden Treasure, and Sunrise Tunnel. The average grade of the ore shipped is shown in the following table:

Dry or siliceous ore, with average metallic content, produced in Ophir and Rush Valley districts and shipped to smelters, 1903–1917.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
1903	200	$1.55	145.00	....	....	$79.85
1904	141	2.20	79.00	....	....	48.02
1905	17	3.65	41.53	0.69	....	31.12
1906	40	1.45	65.00	....	....	45.65
1907	180	2.55	87.40	....	0.98	61.28
1908	206	1.58	104.67	....	.38	57.37
1909	193	1.84	74.48	....	1.20	41.59
1910	72	2.02	48.79	....	.94	29.22
1911	49	2.10	69.49	....	....	38.94
1912	386	2.25	53.82	....	1.16	36.08
1913	250	1.35	43.79	.03	1.26	29.01
1914[a]	....	....	....	....	....	....
1915	15	1.47	61.80	.02	1.08	34.60
1916	284	.80	29.10	.03	1.20	23.06
1917	114	3.58	47.26	.35	2.10	48.09

[a] None.

COPPER ORE.

The copper ores include those carrying over 2½ per cent copper. The Hidden Treasure and Eureka-Ophir properties shipped most frequently during the last decade. The average grade of the ores was as follows:

Copper ore, with average metallic content, produced in the Ophir and Rush Valley districts and shipped to smelters, 1903–1917.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
1903	100	....	21.00	33.58	....	$103.34
1907	52	....	....	4.00	....	16.00
1910	106	....	3.15	16.84	....	44.48
1911	70	....	4.50	22.48	....	58.54
1912	19	....	1.95	26.85	....	89.84
1913	104	....	1.78	16.85	....	53.38
1914	127	....	7.46	17.20	....	49.86
1915	138	....	.62	18.10	....	63.68
1916	4,835	....	10.10	4.87	....	30.69
1917	227	....	5.95	7.70	....	47.99

LEAD ORE AND CONCENTRATES.

In general, the crude lead ore is that containing over 4½ per cent of lead. The producers during the last decade, named according to the frequency of their shipments, were the Ophir Hill, Honerine, New Stockton, Galena King, Cliff, Jay Bird, Bullion Coalition, Buckhorn, Black Diamond, Silver Eagle, Queen of the Hills, Southport, Muerbrook, Hidden Treasure, Cyclone, Honerine West, Honerine Extension, Monadnock, Utah Queen, Commodore, Eureka Ophir, Grand Cross, Northern Light, Miner's Delight, Argenta, Lion Hill, Quandary, Emilie, Lost Boy, Buffalo, Brooklyn, Mono, and Ben Harrison. The average grade of the products shipped is shown in the following table:

Lead ore and concentrates, with average metallic content, produced in the Ophir and Rush Valley districts and shipped to smelters, 1903–1917.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
Crude ore.						
1903	348	$0.29	15.29	0.65	30.55	$36.00
1904	4,856	.55	11.50	....	34.26	36.70
1905	2,506	.74	12.90	.43	27.87	36.15
1906	8,085	.59	9.77	.45	18.07	29.58
1907	14,742	.37	10.70	.04	16.18	24.73
1908	10,698	.22	10.73	.47	21.77	25.43
1909	14,026	.24	8.55	.50	17.33	20.91
1910	18,330	.25	8.11	.46	16.53	20.35
1911	24,426	.59	10.29	.38	18.67	23.82
1912	31,099	.47	10.09	.54	19.13	25.67
1913	22,975	.44	9.59	.45	15.90	21.63
1914	19,536	.42	13.69	.81	17.03	23.43
1915	27,425	.26	12.32	1.67	13.76	25.29
1916	38,081	.22	10.66	1.40	12.35	31.10
1917	35,081	.47	10.76	1.91	11.16	39.00
Concentrates.						
1904	11,274	$0.31	10.86	0.02	38.43	$39.71
1905	4,120	1.33	9.63	....	30.48	35.85
1906	22,366	.36	11.84	3.09	20.92	44.20
1907	26,875	.32	10.74	1.30	14.36	27.84
1908	18,248	.11	12.26	2.60	8.20	20.31
1909	9,976	.24	12.21	2.42	10.37	21.81
1910	109	.57	12.56	.93	22.45	29.46
1912	9,909	.17	12.23	2.39	10.24	24.82
1913	27,376	.19	11.73	2.02	10.87	23.10
1914	23,471	.27	11.60	1.94	12.65	21.72
1915	28,077	.18	11.31	1.68	13.06	24.65
1916	27,642	.19	11.42	1.89	13.72	35.93
1917	13,889	.15	11.57	2.03	13.50	68.11

COPPER-LEAD ORE AND CONCENTRATES.

Copper-lead ore and concentrates are classified like the copper and lead ores. The pro-

ducers for the past decade, named according to the frequency of their shipments, are the Eureka-Ophir, Hidden Treasure, Mono, Ophir Hill, Utah Queen, Kearsarge, Queen of the Hills, Montana, Surprise Tunnel, and Selah. The average grade of the product shipped is shown in the following table:

Copper-lead ore and concentrates, with average metallic content, produced in the Rush Valley and Ophir districts and shipped to smelters, 1903–1917.

Crude ore.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
1903.....	68	$3.64	29.15	3.23	20.44	$45.39
1904.....	150	....	19.00	12.00	28.05	65.86
1905.....	62	.34	6.92	7.77	5.81	34.27
1906.....	603	.82	11.07	9.47	9.12	55.30
1907.....	192	1.02	18.10	6.39	10.04	49.15
1908.....	51	.78	18.78	7.91	13.48	42.98
1909.....	819	.05	13.31	6.94	14.71	37.67
1910.....	1,218	.40	16.14	3.95	10.72	28.57
1911.....	694	.30	14.85	5.04	20.10	38.86
1912.....	3,387	1.04	40.95	4.32	12.58	51.82
1913.....	1,419	.18	12.90	4.57	18.63	38.53
1914.....	51	.98	18.08	4.55	17.72	36.92
1915.....	5,016	.24	12.66	3.22	8.57	25.99
1916.....	2,072	.27	19.28	3.61	16.57	53.58
1917.....	5,536	.22	12.90	2.84	11.09	45.48

Copper-lead ore and concentrates, with average metallic content, produced in the Rush Valley and Ophir districts and shipped to smelters, 1903–1917—Continued.

Concentrates.

Year.	Quantity (short tons).	Gold (value per ton).	Silver (ounces per ton).	Copper (per cent).	Lead (per cent).	Average gross value per ton.
1903.....	14,210	$0.24	15.85	3.20	9.12	$25.18
1904.....	16,707	.20	13.47	2.94	7.07	21.63
1905.....	19,062	.18	13.03	3.46	9.19	27.58
1907.....	8	1.00	30.00	4.70	21.00	61.87

ZINC ORE AND CONCENTRATES.

The zinc ores are those containing 25 per cent or more of zinc, irrespective of precious metals. Carbonates prevailed and some sulphides were included in the shipments. The shippers were the Hidden Treasure, Cliff, and Bullion Coalition.

The average grade of the ores is omitted, as there was only one shipper of concentrate in 1913 and only two in 1912 and 1913.

PRODUCTION.

The metal production of Ophir and Rush Valley districts from the beginning of operations to 1917 is shown in the following tables:

Metals produced in Ophir and Rush Valley mining districts, 1901–1917.

Year.	Ore.	Gold.		Silver.		Copper.		Lead.		Recoverable zinc.		Total value.
	Short tons.	Fine ounces.	Value.	Fine ounces.	Value.	Pounds.	Value.	Pounds.	Value.	Pounds.	Value.	
1901 [a]	30,000	227.51	$4,703	318,910	$191,346	1,199,476	$200,312	4,557,818	$195,986	....	....	$592,347
1902	34,611	228.33	4,720	259,805	137,697	913,622	111,462	3,609,186	147,977	....	....	401,856
1903	36,238	186.97	3,865	261,838	141,393	966,291	132,382	2,584,151	108,534	....	....	386,174
1904	81,716	479.01	9,902	417,397	238,960	1,023,825	127,978	14,440,385	631,767	....	....	1,008,607
1905	79,603	530.00	10,956	321,556	194,220	1,093,197	170,539	6,805,814	319,873	....	....	695,588
1906	78,257	647.88	13,393	353,036	236,534	1,570,689	303,143	2,391,100	706,293	....	....	1,259,363
1907	98,559	719.63	14,876	465,863	307,469	739,521	147,904	12,535,190	664,365	....	....	1,134,614
1908	55,604	236.34	4,886	359,992	190,796	1,059,138	139,806	7,676,385	322,408	....	....	657,896
1909	53,981	301.21	6,226	266,436	138,547	738,299	95,979	7,154,721	307,653	....	....	548,405
1910	20,247	257.89	5,332	174,145	94,039	307,607	39,066	7,908,992	347,995	....	....	486,432
1911	25,773	719.95	14,882	266,141	141,054	289,329	36,166	9,406,042	423,272	333,876	$19,031	634,405
1912	99,976	1,418.28	29,318	531,475	326,857	1,065,384	175,788	17,250,387	776,268	373,870	25,797	1,334,028
1913	89,658	822.05	16,992	577,348	348,719	1,492,073	231,271	14,054,788	618,410	778,162	43,577	1,258,969
1914	95,446	701.32	14,498	541,652	299,533	1,277,015	169,843	12,611,432	491,846	732,367	37,351	1,013,071
1915	111,352	735.73	15,208	728,309	369,253	2,250,276	393,799	16,383,700	770,034	1,198,172	148,573	1,696,867
1916	119,163	799.30	16,523	833,116	548,190	2,821,108	693,993	18,275,389	1,261,002	776,866	104,100	2,623,808
1917	91,657	986.45	20,392	618,542	509,679	2,277,022	621,627	12,896,789	1,109,124	630,018	64,262	2,325,084
	[b] 1,201,841	9,997.85	206,672	7,295,561	4,414,286	21,083,872	3,791,058	170,542,269	9,202,807	4,823,331	442,691	18,057,514

[a] Partly estimated.

[b] Some lead and copper-lead concentrate produced.

Metals produced in Ophir and Rush Valley mining districts, 1870–1917, by periods.

Period.	Gold.		Silver.		Copper.		Lead.		Recoverable zinc.		Total value.
	Fine ounces.	Value.	Fine ounces.	Value.	Pounds.	Value.	Pounds.	Value.	Pounds.	Value.	
1870–1880	12,436.25	$257,080	3,885,938	$4,789,719	....	....	77,582,430	$4,335,597	....	....	$9,382,396
1881–1890	2,548.99	52,713	1,502,643	1,499,742	....	....	10,377,100	447,930	....	....	2,000,385
1891–1900	3,411.06	70,513	1,575,538	1,114,951	1,942,682	$253,315	17,358,239	657,364	....	....	2,096,143
1901–1910	3,814.77	78,859	3,198,978	1,871,001	9,611,665	1,468,571	69,663,742	3,752,851	....	....	7,171,282
1911–1917	6,183.08	127,813	4,096,583	2,543,285	11,472,207	2,322,487	100,878,527	5,449,956	4,823,331	442,691	10,886,232
	28,394.15	586,978	14,259,680	11,818,698	23,026,554	4,044,373	275,860,038	14,643,698	4,823,331	442,691	31,536,438